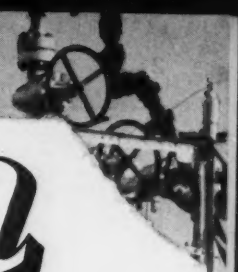
CHNOLOGY DEPT.

Corrosion



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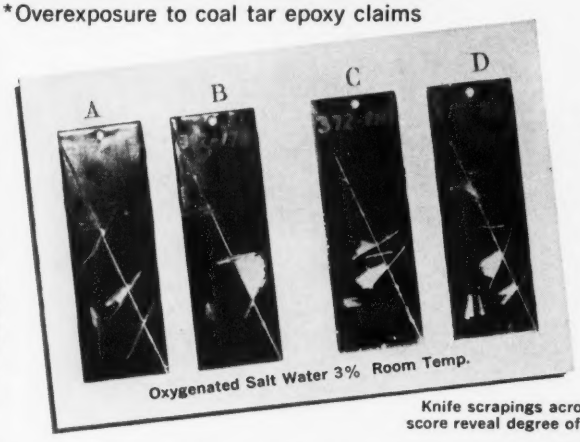
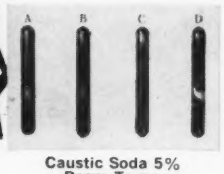
SUFFERING FROM COALTAREPOXICATION?*

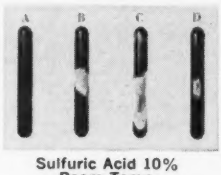
*Overexposure to coal tar epoxy claims



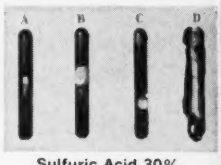
Knife scrapings across diagonal score reveal degree of undercutting.



Caustic Soda 5%
Room Temp.

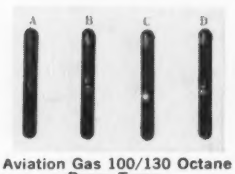


Sulfuric Acid 10%
Room Temp.

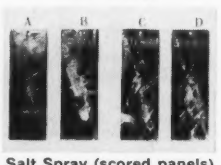


Sulfuric Acid 30%
Room Temp.

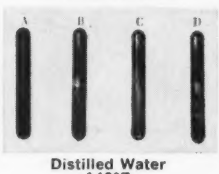
Sodium Hypochlorite 5%
Room Temp.



Aviation Gas 100/130 Octane
Room Temp.

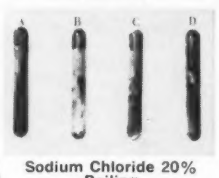


Salt Spray (scored panels)
Room Temp.

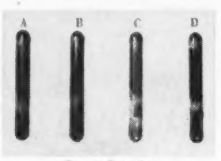


Distilled Water
140°F

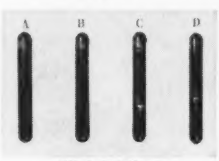
Distilled Water
Boiling



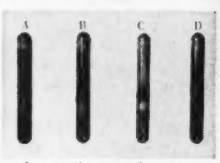
Sodium Chloride 20%
Boiling



Sour Crude
120°F



JP-4 Jet Fuel
120°F



Aromatic petroleum
hydrocarbon solvent—120°F

Try these tests to end the confusion

116

So many conflicting claims have been made about virtually every coal tar epoxy coating on the market that prospective users are finding it difficult to fish out the facts from a sea of superlatives.

Perhaps you can find *your* answer by duplicating any or all of these laboratory tests comparing the four leading coal tar epoxies.

THE TESTS: The rods and panels illustrated here were carefully coated to the four manufacturers' specifications and then subjected for three months to the corrosive agents indicated above. The wide range of tests included varying concentrations of chemicals, ambient and elevated temperatures, weathering and all usual types of exposure.

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CONFIRMATION: The properties attributed to No. 78 in these tests have been substantiated repeatedly in actual field use. Applicators like it because it (1) gives dependable, all-around protection, (2) sprays more easily than competitive products, (3) builds thick films without difficulty because of its higher solids content, and (4) dries thoroughly but at a moderate rate, avoiding the extremes of prolonged tackiness and fast-dried brittleness.

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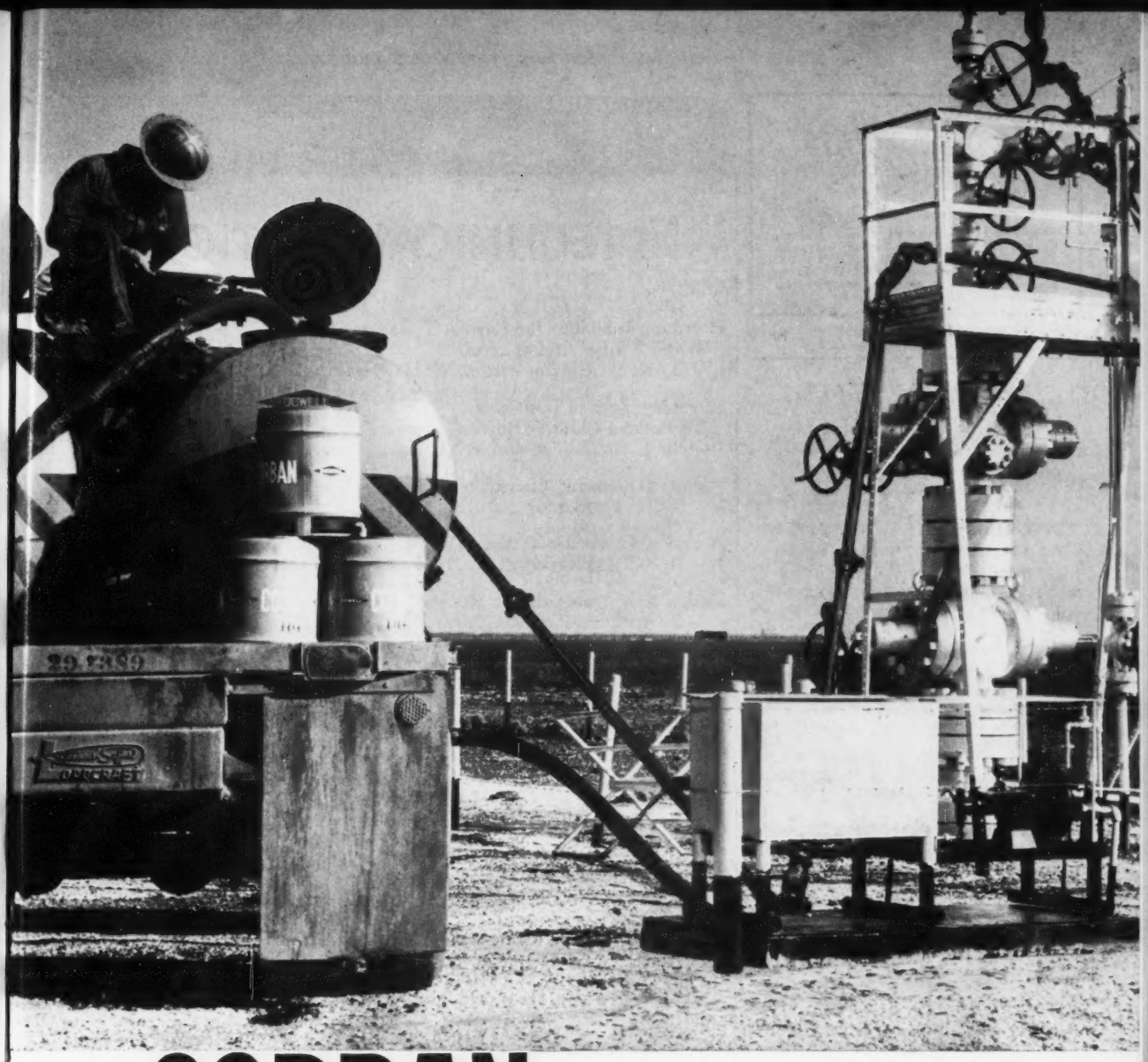

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Platinum Anodes for Cathodic Protection of Active Ships
Instruments for Measurements in Underground Corrosion Work
Equivalent Electrical Circuit Analogy of Structure-to-Soil Potentials

#

SOME FUNDAMENTAL ASPECTS OF MATERIALS DETERIORATION IN THE ATMOSPHERE—See Page 111 this issue for details

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A Modern Approach to Planning a Maintenance Coating Program for Pulp and Paper, by M. W. Belue

Effects of Foreign Metals on Corrosion of Titanium in Boiling 2N Hydrochloric Acid, by W. Roger Buck, III, Billy Sloppe and Henry Leidheiser, Jr.

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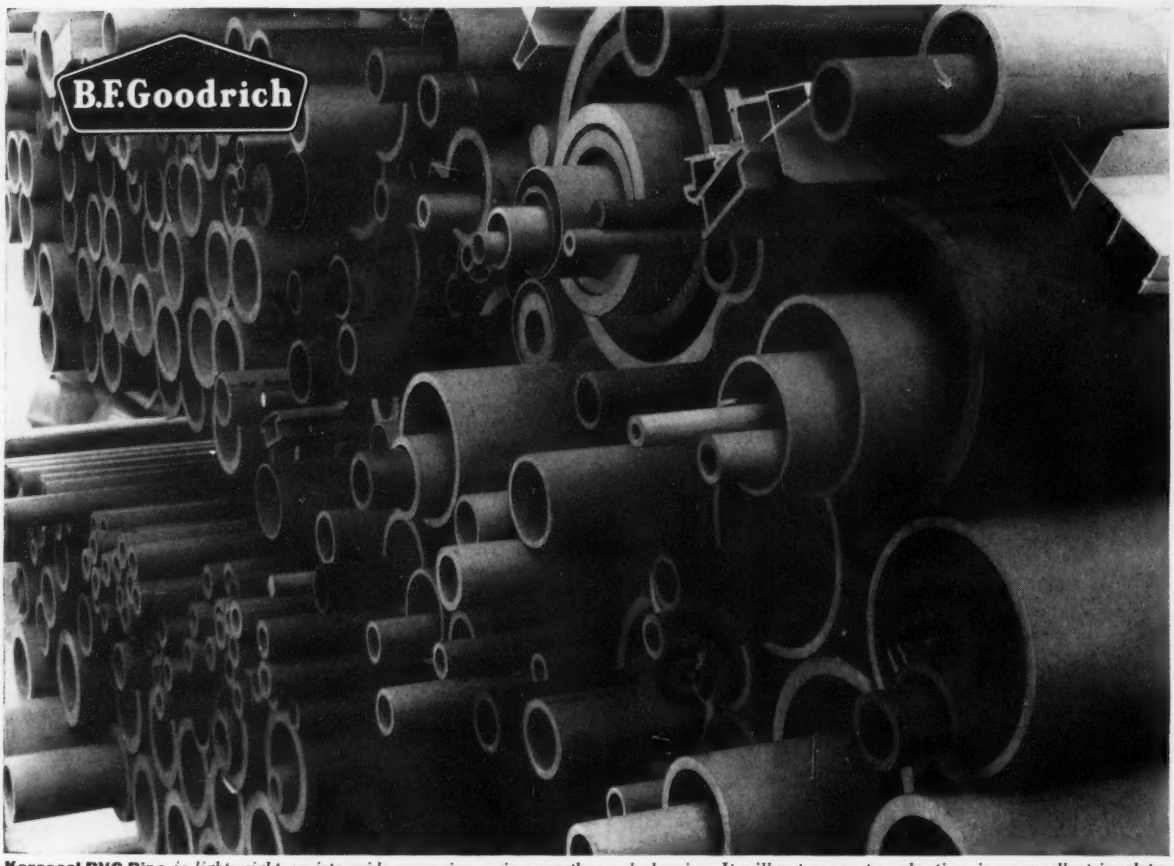

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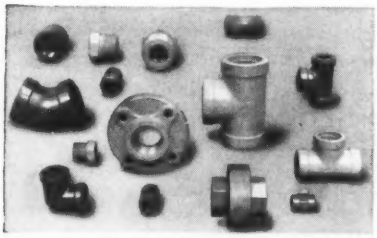

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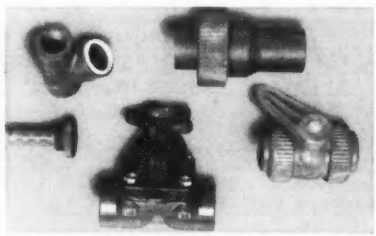

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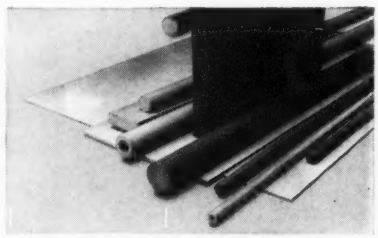

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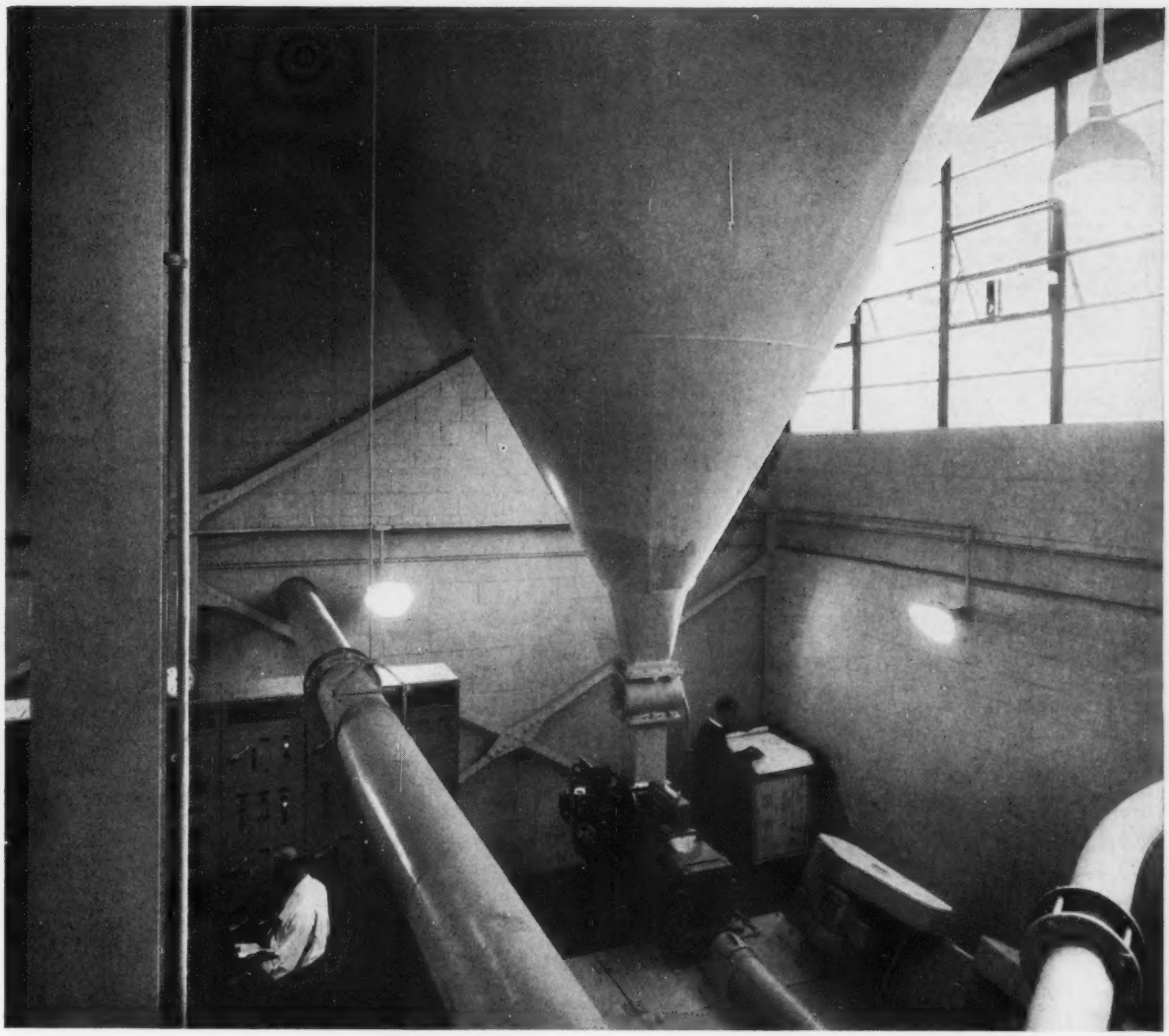

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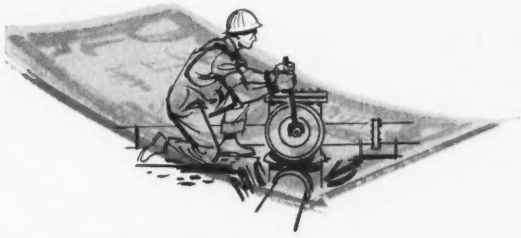

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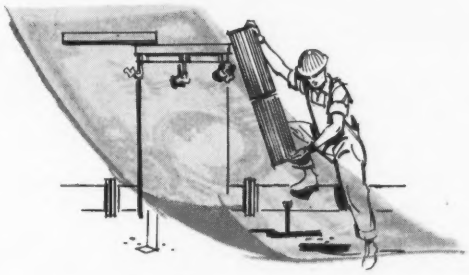

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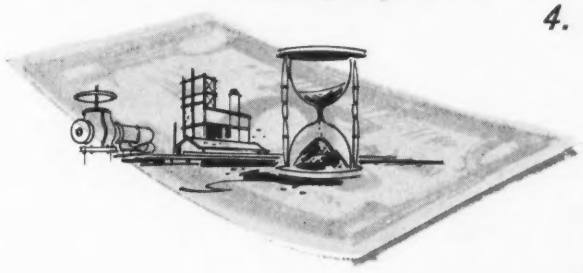

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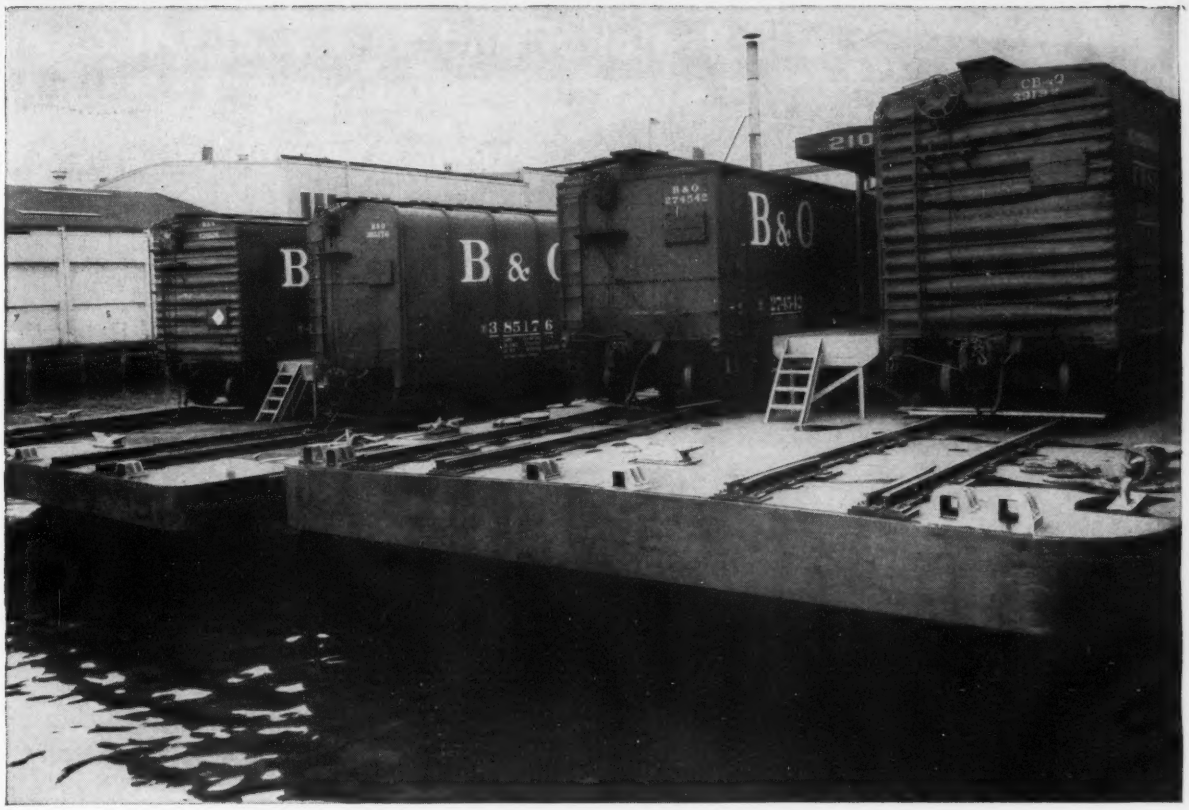

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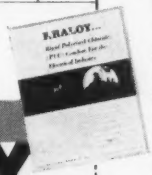

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Corrosion Inhibitors for Carbon Tetrachloride—Water Vapor Atmospheres*

By K. W. CALKINS and R. W. HAWLEY

Abstract

The use of various inhibitors for the prevention of mild steel corrosion in a system of carbon tetrachloride and water vapor was investigated. An attempt also was made to establish a corrosion mechanism. Of the 48 inhibitors tested, 2-aminoethanol appeared to be the most effective. It was found that 0.4 percent by weight of 2-aminoethanol in carbon tetrachloride decreased the corrosion rate of mild steel in a carbon tetrachloride-water vapor atmosphere by 99 percent. The next most effective inhibitor decreased the rate by about 95 percent.

Introduction

DURING THE course of work conducted in an enclosed, unventilated space, extreme corrosion of mild steel was experienced, presumably due to the presence of carbon tetrachloride and normal atmospheric moisture. In the work reported here, an attempt was made to determine the probable corrosion mechanism. Also a search was conducted for a suitable corrosion inhibitor.

Theory

Although no attempt has been made to conduct an extensive theoretical study, some preliminary work was done to establish a possible reaction mechanism.

At the outset, a test was performed to determine whether or not carbon tetrachloride was the actual corrosion agent. Following the procedure outlined in a later section, corrosion rates of mild steel were measured in a carbon tetrachloride-water vapor atmosphere and in a kerosene-water vapor atmosphere. The absence of CCl_4 was found to reduce the corrosion rate to a minimum.

It was then postulated that the CCl_4 in the work space was reacting by hydrolysis with the water vapor, forming hydrochloric acid and phosgene according to the following reaction:

$$CCl_4 + H_2O \rightarrow COCl_2 + 2HCl$$

Since it is well known[1,2] that this reaction readily occurs at elevated temperatures but only slightly at room temperatures, tests were made to determine the possibility of this mechanism.

In this series, corrosion data and quali-

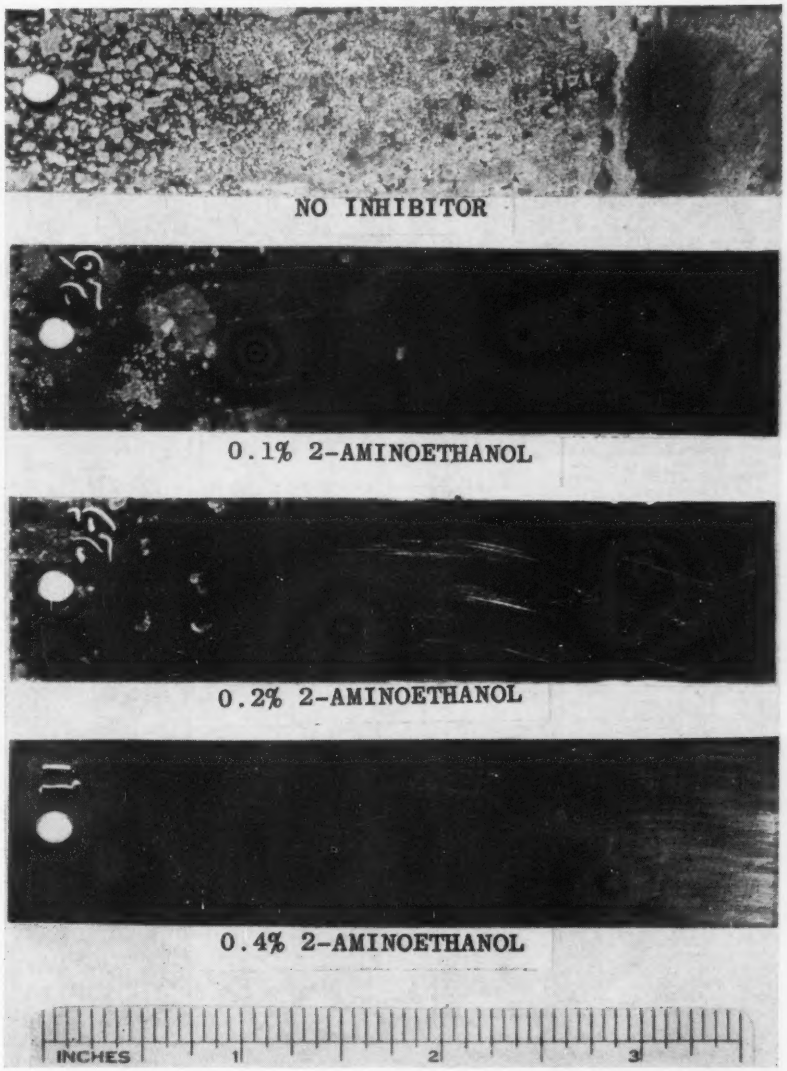

Figure 1—Mild steel exposed seven days to carbon tetrachloride-water vapor atmosphere.

★ Submitted for publication May 13, 1957.

Calkins

Hawley

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tative phosgene indications were obtained in a number of systems involving combinations of CCl_4, water, water vapor, kerosene, and mild steel. In addition, the samples of CCl_4 used were extracted with an equal volume of water, and the extract analyzed for acidity and pH. From the results, as shown in Table 1, it can be seen that little or no acidity is present in the fresh CCl_4 and that only a small amount is formed after contact with water vapor at room temperature. Only after exposure to the metallic surface was a significant concentration of acid present in the CCl_4. Furthermore, no more than a trace of phosgene was indicated in any system except the one which included CCl_4, water vapor, and mild steel. From these indications, it was concluded that the metal must act as a catalyst in the above postulated reaction, allowing the formation of HCl.

The last test shown in Table 1 was made after completion of the search for a suitable inhibitor. This inhibitor is shown not only to reduce the acidity to zero, but to supply some alkalinity, as well as to form a protective film.

In addition to the above data, the scale formed on the uninhibited corrosion samples was analyzed miscroscopically and found to be predominantly iron chloride, while the very small amount of scale in spots on the inhibited corrosion samples was primarily iron oxides.

Procedure

The corrosion tests were performed by placing a cleaned 1 inch x 4 inch 16-

TABLE 1—Test System Conditions

System	Exposure, Days	Corrosion Rate, mpy	Phosgene*	Extract Acidity, ppm HCl	Extract pH
CCl_4-H_2O vapor-Mild Steel	7	33.9	4	256	2.6
Kerosene-H_2O vapor-Mild Steel	7	0.1	0	0	7.9
CCl_4-Mild Steel	7	0.1	1	0	7.8
H_2O vapor-Mild Steel	7	0.8	0	..	..
CCl_4-H_2O vapor	7	...	1	8	5.6
CCl_4	..	...	0	1	6.4
H_2O-Mild Steel	7	18.0	0	0	7.5
CCl_4-H_2O vapor-Mild Steel + 0.4% 2-aminoethanol	7	0.2	0	23**	8.5

* Qualitative measurement, see Reference 3, p. 335; Phosgene indication increases in order: $0<1<2<3<4$.
** Alkalinity as ppm NaOH.

TABLE 2—Inhibitors for Mild Steel Corrosion in CCl_4-H_2O Vapor Atmospheres

Inhibitor or Special Solution	Concentration, Percent	Exposure Days[1]	Corrosion Rate mils/yr
None[2]	.....	7-28	33.9
None (50 C)	.....	7	75.8
2-aminoethanol	0.1	7	2.2
2-aminoethanol	0.2	7	1.1
2-aminoethanol	0.4	7	0.2
2-aminoethanol	0.4	21	0.1
2-aminoethanol (50 C)	0.4	7	23.8
1, 2-propanediamine	0.2	7	7.3
1, 2-propanediamine	0.4	7	1.8
2, 2-iminodiethanol	0.4	7	4.3
1-naphthol	0.4	7	0.2
1-naphthol	Saturated	7	1.1
1, 2-propanediamine	0.2	7	3.4
2, 2-iminodiethanol	0.2		
2, 2-iminodiethanol	0.2	7	3.5
1-ethynylcyclohexanol	0.2		
2, 2-iminodiethanol	0.2	7	3.5
2-methyl-3-butyn-2-ol	0.2		
2, 2-iminodiethanol	0.2	7	3.4
1, 2-propanediamine	0.2		
2, 2-iminodiethanol	0.2		
2-dimethylaminoethanol	0.2	7	3.8
2-aminoethanol	0.1		
2-methyl-3-butyn-2-ol	0.1	7	3.2
1-naphthol	Saturated	7	0.6
2-aminoethanol	0.2		
1-naphthol	Saturated	7	0.9
2-aminoethanol	0.1		
1-naphthol	50% Saturated 0.2	7	0.3 and 0.6
2-aminoethanol			
Acetaldehyde	0.4	7	18.5
1-Allyl-2-Thiourea	0.4	7	11.3
Ammonia Atmosphere	.	7	18.8
Benzaldehyde	0.4	7	22.4
Benzoyl Peroxide	0.4	7	4.9
Benzylamine	0.4	7	12.2
N-Butylamine	0.4	7	26.1
Sec-Butyl Alcohol	0.4	7	34.1
Carbon Disulfide	0.4	7	38.8
Catechol	0.4	7	2.1
2-Chloroethanol	0.4	7	23.9
Chlorothene[3]	[4]	7	8.7
P-Cresol	0.4	7	15.6
Cyclohexane	0.4	7	33.3
Diethylcyanamide	0.4	7	27.8
Di-Isobutylene	0.4	7	26.7
Diisopropylamine	0.4	7	22.8
Dimethylaminoethanol	0.4	7	5.2
Dioxane	0.4	7	41.3
Diphenylamine	0.4	7	29.3
1-Ethynyl Cyclohexanol	0.4	7	42.3
Hydrazine	0.4	7	31.2
N-Methylaniline	0.4	1	25.8
2-Nethylbutane	0.4	7	32.0
2-Methyl-3-Butyn-2-ol	0.4	7	26.6
3-Methylcyclohexanol	0.4	7	19.5
N-Methylmorpholine	0.4	7	8.6
3-Methyl-1-Pentyn-3-ol	0.4	7	11.2
Morpholine	0.4	7	5.5
Morpholine	0.2	7	7.9
2-Methyl-3-Butyn-2-ol	0.2		
1-Naphthylamine	0.4	7	13.2
Pentene	0.4	7	17.6
M-Phenylenediamine	0.4	7	1.5
Polyrad[5]	0.4	7	19.8
2-Propyn-1-ol	0.4	7	5.8
Pyridine	0.4	7	13.4
Pyrogallic Acid	0.4	7	38.9
Resorcinol	0.4	7	22.2
Toluhydroquinone	0.4	7	4.0
Triethanolamine	0.4	7	19.7
Triethanolamine	[6]	7	13.9
Triethanolamine	0.2	7	6.4
1-ethynyl cyclohexanol	0.2		
Triethylamine	0.4	7	33.2
Urea	0.4	7	47.1

[1] Room temperature unless otherwise noted.
[2] Average of six separate tests.
[3] Trademark for inhibited 1, 1, 1-trichloroethane, manufactured by The Dow Chemical Company.
[4] This material was tested as a substitute for carbon tetrachloride.
[5] Polyrad 1110a, a water soluble derivative of an organic amine manufactured by the Hercules Powder Company.
[6] Triethanolamine was painted on the metal coupon before immersion in carbon tetrachloride.

gauge mild steel coupon in an 8-oz. jar containing sufficient inhibited or uninhibited carbon tetrachloride to cover 1 inch of the coupon. A sponge saturated with water was supported near the top of the jar to supply a 100 percent relative humidity atmosphere. The jar was sealed and maintained at room temperature for the test period. Elevated temperature tests were made in a constant temperature bath.

Each coupon was weighed prior to the test and again at completion—usually 168 hours (7 days.) Before the final weighing, each coupon was scrubbed in water and detergent with a soft brush to remove the scale that had been formed. The coupon was then rinsed in acetone for drying.

A total of 82 runs were made to test 48 inhibitors in the CCl_4-H_2O vapor atmosphere, including 2 tests of the most promising inhibitor at 50 C. In addition, the selected inhibitor was tested on water corrosion alone at room temperature and at 50 C. These latter tests were conducted because of possible future operating requirements.

Results

The results of the tests, exclusive of those reported elsewhere, are tabulated in Table 2. For convenience, the control tests with no inhibitor are listed first, followed by the items which were found to be most satisfactory. The balance of the list is presented to show the various inhibitors tested without significant success. Figure 1 shows a typical control sample and a series of 2-aminoethanol-inhibited coupons.

Of the inhibitors tested, 2-aminoethanol, or monoethanolamine, was found to be the most effective. When used in a 0.4 percent mixture based on CCl_4, corrosion was essentially stopped, and the surface remained bright and shiny. Some other inhibitors such as 1, 2-propanediamine, 2, 2-iminodiethanol, 1-naphthol, and mixtures of these and other chemicals showed good results, but failed to equal 2-aminoethanol. The 1-naphthol, although a good inhibitor, left a thick brown deposit on the test coupon. This film was removed by brushing.

TABLE 3—Test Results

System	Exposure Days	Corrosion Rate, mpy
CCl_4-H_2O Vapor (Control)	7	33.9
H_2O	7	18.0
H_2O + 0.2% 2-aminoethanol	7	0.3
H_2O at 50 C	28	24.0
H_2O + 0.2% 2-aminoethanol*	28	0.6
CCl_4-H_2O Vapor-CO_2	7	36.7
CCl_4-H_2O Vapor-CO_2 + 0.4% 2-aminoethanol	7	0.6
CCl_4-H_2O Vapor + 0.4% 2-aminoethanol	7	0.2
CCl_4-H_2O Vapor-Saturated in 2-aminoethanol	7	5.5

* at 50C

One test with 2-aminoethanol was continued for a total of 504 hours (21 days.) The corrosion rate was found to be nearly constant with time.

In addition to the tests performed in the search for an inhibitor, several others of interest were made. They are described in the following paragraghs, and shown in Table 3.

To determine the usefulness of 2-aminoethanol as an inhibitor of water corrosion alone, two tests were made at room temperature, and two at 50 C. The filming action of the amine acted as a very efficient inhibitor at both temperatures.

Since there was some feeling that the presence of CO_2 might affect the corrosion rate of metal in contact with the CCl_4-H_2O vapor system, two tests were made with CO_2 by adding pieces of dry ice to the test bottle and allowing it to sublime into the vapor space. The results indicate that CO_2 has little effect in the corrosion rate. A possible effect might be a very slight increase in the rate.

A series of tests was made to determine a method of inhibitor addition. It was thought that the addition of the inhibitor to the CCl_4 followed by a period of agitation would yield a solution ready for use. By comparison, with a 0.4 percent solution, it can be seen that inhibition of a saturated solution was not satisfactory. The 0.4 percent solution is somewhat more than saturated, and a small amount of inhibitor saturated with CCl_4 is seen to float on the top of the solution. This small amount probably contributes measurably to the concentration in the vapor phase and helps to reduce the corrosion. From these data it is apparent that to be effective, the 2-aminoethanol must be present in an amount greater than saturation; therefore, it may be desired to apply the inhibitor from a continuously agitated reservoir in order to maintain a 0.4 percent solution.

It was noticed that most of the inhibitors tested, as listed in Table 2, were also more than saturated in CCl_4 at the concentration given, thus reducing the difference in results which might be attributed to varying solubility.

Conclusions

The use of 0.4 percent by weight of 2-aminoethanol in carbon tetrachloride was found to decrease by 99 percent the corrosion rate of mild steel in a carbon tetrachloride-water vapor system. The next most effective inhibitor decreased the rate by about 95 percent. The use of 2-aminoethanol also was found to reduce corrosion substantially in the same system at 50 C.

Acknowledgments

The authors acknowledge the aid of F. N. Alquist and L. Wasco of the Edgar C. Britton Research Laboratory of The Dow Chemical Company, Midland, Michigan, for their helpful suggestions and list of possible inhibitors. W. A. Rains, presently of the Nuclear and Basic Research Laboratory, performed many of the early inhibitor tests. The General Laboratory of the Rocky Flats Plants performed all of the chemical analyses.

References

1. R. K. Taylor. Action of Carbon Tetrachloride on Silica Gel. *Journal Am. Chem. Soc.*, 75, 1953).
2. B. Sjoberg. Thermal Decomposition of Chlorinated Hydrocarbons. *Svensk Kem. Tid.*, 64 (1952). (In English)
3. F. J. Welcher. Chemical Solutions. Van Nostrand, New York (1942).

Any discussion of this article not published above will appear in the December, 1959 issue

Evaluation of Performance

Screening Tests of Inhibitors to Prevent Chloride Stress Corrosion*

By J. H. PHILLIPS and W. J. SINGLEY

Abstract

Series of screening tests were run in tilting autoclaves to evaluate performance of selected, potential inhibitors in preventing chloride stress corrosion attack of Type 347 austenitic stainless steel in alkaline-phosphate boiler water containing 50 or 500 ppm chloride. From the test results, several inhibitors were tested further to evaluate concentration effects. Nitrate appeared to be a satisfactory inhibitor for boiler applications. Sodium sulfite also effectively prevented chloride corrosion cracking by scavenging oxygen. 5.8.4

Introduction

STRESS CORROSION attack of austenitic stainless steels in chloride solution has received widespread attention in recent years. Numerous papers, a few of which are cited here,[1, 2, 3] have discussed case histories and laboratory studies of stress corrosion cracking of austenitic stainless steel systems. With the advent of the pressurized water nuclear power plant, considerable effort has been devoted to finding methods of preventing chloride stress corrosion attack because of the numerous austenitic stainless steel surfaces exposed to hot water.

Primary attention has been devoted to the stainless steel tubed steam generators in the nuclear power plants for the following reasons:

1. The steam generator is one of the most likely points in the plant for high concentrations of chloride to occur.

2. Cracking of the thin-walled tubing (0.050 to 0.070 in.) used in the steam generator cannot be tolerated because of the long term integrity requirements and desirability of maintenance free operation for reactor plant components.

3. In addition to possible high chloride concentrations in the steam generator, other conditions believed to accelerate stress corrosion attack exist such as presence of oxygen and steam blanketed areas.

Work described in this article was concerned with attempts to develop methods for preventing chloride stress corrosion attack of austenitic stainless steel by modification of the water environment. Specifically, an inhibitor or water treatment was sought to prevent chloride stress corrosion attack of Type 347 stainless steel.

The stress corrosion inhibitor program was conducted in three phases:

Phase 1—Screening tests of potential inhibitors to select those considered desirable for further investigation.

Phase 2—Extensive evaluation of inhibitors selected on the basis of the Phase 1 results under variable test conditions. Variable test conditions studied included chloride concentrations, oxygen concentrations, stainless steel composition and inhibitor concentrations and combinations.

Phase 3—Testing of the most promising inhibitors selected from Phases 1 and 2 in model boilers. Phase 3 is in progress; results will be published later.

★Submitted for publication April 1, 1959. A paper presented at a meeting of the North Central Region Conference, National Association of Corrosion Engineers, October 15-17, 1958, Cincinnati, Ohio.

Selection of Inhibitors

Basis for selection of the inhibitors was arbitrary because little work had been conducted on stress corrosion inhibitors and knowledge of the stress corrosion attack mechanism was insufficient to predict what chemical action would be required. An attempt was made to select representative chemicals from broad categories as listed below. In addition to the requirement that inhibitors should protect against chloride stress corrosion attack, it was deemed necessary that the inhibitors should be stable thermally under boiling conditions at 500 F in an essentially oxidizing atmosphere containing up to 0.5 ppm oxygen. The practical problems of inhibitor injection and control in steam generator application were also considered in making selections.

1. Oxygen Scavengers: Previous testing indicated that oxygen was a strong accelerator of chloride stress corrosion, and it was believed that elimination of oxygen would prevent attack.[3, 4, 5]

2. Complexing Agents: It was believed that compounds which complex iron or nickel might modify the surface of stainless steel so that the surface would be resistant to chloride stress corrosion.

3. Film Forming and Neutralizing Compounds: Some film forming and neutralizing amines such as octadecylamine and morpholine have been successful in minimizing corrosion in steam and condensate systems. Volatile film forming compounds were tested in the inhibitor program to determine whether a protective film could be formed on austenitic stainless steel.

4. Localized Corrosion Inhibitors: At least one inhibitor, sodium nitrate, was selected for test because it was known to be effective for preventing caustic stress corrosion of carbon steel in boilers.

5. General Corrosion Inhibitors: Several inhibitors were tested because of their known effectiveness for minimizing general corrosion of austenitic stainless steel and/or carbon steel. It was recognized in selecting potential inhibitors for this category that the mechanism of pro-

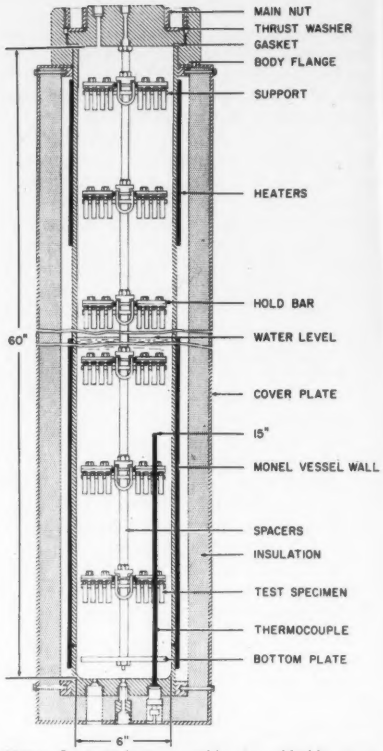

Figure 1—Autoclave assembly for chloride stress corrosion tests.

Phillips

Singley

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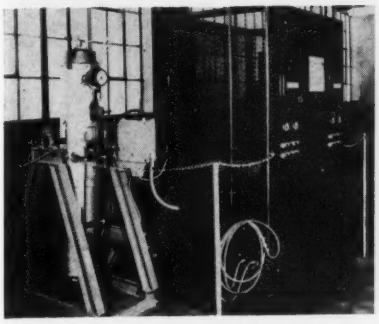

Figure 2—Tilting autoclave installation.

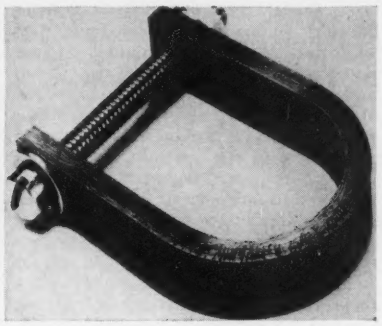

Figure 3—Typical stress corrosion cracking observed on Type 347 stainless steel stressed U-bend specimen exposed to synthetic boiler water containing 500 ppm chloride.

TABLE 1—Properties of Type 347 Stainless Steel Used for Fabrication of U-bend Specimens

Constituent %	Range % Type 347 Stainless Steel	Phase 1	Phase 2			
			Heat A	Heat B	Heat C	Heat D
Chemical Analysis						
Chromium	17.00-19.00	17.80	17.70	18.0	18.1	17.90
Nickel	9.00-12.00	10.80	11.15	10.78	11.1	10.75
Carbon	0.08 max.	0.060	0.04	0.05	0.065	0.05
Manganese	2.00 max.	1.62	1.70	1.66	1.72	1.50
Silicon	1.00 max.	0.72	0.54	0.41	0.33	0.21
Niobium	10 X C Min.	0.90	0.64	0.80	0.65	0.68
Phosphorous	.....	0.026	0.028	0.030	0.035	0.028
Sulfur	.....	0.012	0.014	0.011	0.019	0.011
Physical Properties						
Tensile Strength (psi)	80,000	79,900	79,900	84,500	89,000	88,100
Yield Strength (psi)	30,000	39,400	48,200	36,000	41,400	43,300
% Elongation in 2 in.	40.0 min.	44.2	51	50	50	50

tection varies from compound to compound. The category, therefore, included inhibitors with divergent properties including organic compounds, inorganic compounds with oxidizing properties and inorganic compounds without oxidizing properties, but effective in oxidizing media.

Test Program

Apparatus

Selection of a tilting autoclave as the most satisfactory type equipment for Phases 1 and 2 of this program was based on several significant factors. The following criteria are among those which favored the autoclaves use for evaluating the various chemical categories selected:

1. Duplication of steam generator temperature and pressure conditions.
2. Exposure of multiple specimens to permit statistical evaluation of results.
3. Correlation with previous results in tilting autoclaves.[3, 4, 5]
4. Permit concentration of chlorides on stressed metal surfaces by alternate exposure to vapor and liquid.
5. Sufficiently simple to permit easy and thorough cleaning between tests.

Each of two identical Monel autoclaves, 6 inches inside diameter and 60 inches long with a removable head on one end, was mounted on trunions so that it could be automatically tilted by a motor drive through a 180-degree arc. Each was equipped with a sampling line and sample cooling coil connected to the bottom of the autoclave, a pressure gage and a pressure safety disc in the removable head and suitable high pressure valves in the head for venting and in the bottom and sampling line.

Figure 1 shows a cross sectional view of the autoclave vessel, strip heaters and insulation, thermocouple location and the specimen support rack attached to the inside of the removable head. Figure 2 is an over-all view of the equipment showing one of the autoclaves, trunion and control and instrument panel.

The autoclave was heated by strip heaters mounted on the vessel wall as shown in Figure 1. Solution temperature was controlled at 500 ± 5 F. Test solution temperature was measured by a Monel sheathed thermocouple inserted through the autoclave bottom.

As shown in Figure 1, the specimen support rack which could accommodate a maximum of 96 specimens was suspended from the bottom of the removable head. This permitted assembly of all specimens in the desired location on the rack before lowering into the autoclave and positioning the laminated stainless steel-asbestos gasket and head. The Type 304 stainless steel support was arranged to avoid any vertical or lateral movement of the specimens during test and to avoid contact of the specimens with each other or any autoclave part.

U-Bend Specimens

The U-bend test specimens were fabricated from flat strips 3¾ inches long, ⅛-inch thick and ⅜-inch wide. They were bent into U-shape over a ⅝-inch radius mandrel. Prior to test, the specimens were stressed beyond yield by deflecting the legs of the U inward a measured distance using a Type 304 stainless steel nut and bolt as shown in Figure 3.

All specimens were fabricated from Type 347 stainless steel. The specimens used in Phase 1 were fabricated from a single heat of steel to eliminate any possible variations in results that might be attributed to metal composition.

Specimens used in Phase 2 were fabricated from four additional heats, A, B, C and D, all having a chemical analysis within the tolerance specifications for Type 347 stainless steel. Table 1 shows the chemical analysis of the principal alloying elements in each of the four heats with the AISI specification for Type 347 stainless steel.

Preparation of Test Solutions

All solutions used in this test program were made with high purity water prepared from Chicago tap water by passing it first through a softener containing Nalcite HCR resin, then through a distillation unit to remove organic material and sodium salts. The distilled water was stored in a polyethylene drum until needed for making test solution. At the time the required water volume was drawn for a given test solution, the water was drawn from the drum through a mixed bed deionizing unit composed of one part Nalcite HGR hydrogen form, nuclear grade, and two parts of Nalcite SBR-porous, hydroxide form, nuclear grade to remove the final traces of inorganic impurities.

In one test in which oxygen was scavenged from the water before test solution formulation, an ion exchange column containing Nalcite SAR resin, sulfite form, was installed in the line between the polyethylene drum and the mixed bed deionizing unit. In this test, the container of 15 liters of test solution was blanketed with nitrogen gas during preparation and loading into autoclave to exclude atmospheric oxygen.

All chemicals used for the preparation of test solutions were reagent grade or the highest available purity.

Test Procedure

The operational procedure for all tests was about the same and included the following steps: formulation of test solution; U-bend specimen stressing and inspection for surface flaws prior to test; loading of specimen rack and autoclave; operation of autoclave, periodic sampling of test solution and chemical analysis of samples; removal and inspection of U-bend specimens upon completion of test and metallographic examination of selected specimens.

Formulation of Test Solution, Sampling, and Analysis. Formulations of test solutions using distilled demineralized water and reagent grade chemicals were completed in accordance with the specifications selected for each test. With few exceptions, chemical concentrations were adjusted initially as shown below to constitute a synthetic boiler water solution. Chloride and oxygen were added to the synthetic boiler water solution to provide accelerated chloride stress corrosion conditions.

Chloride: 50 or 500 ppm as Cl added as sodium chloride or dilute synthetic sea water (ASTM specification D-1141-52)

Phosphate: 100 or 300 ppm as PO_4 added as disodium phosphate (Na_2HPO_4).

pH: 10.6 to 11.2 adjusted with sodium hydroxide.

Oxygen: Vapor phase, evacuated for oxygen scavenger tests; air for other inhibitors. Liquid Phase—air saturated (8.0 ppm O_2) at room temperature.

Unfiltered samples were analyzed periodically during each test for oxygen, chloride, phosphate and inhibitor concentration. The pH of the samples was also read on a pH meter.

Specimen Preparation. All specimens were inspected before stressing with a 10-power eye piece. After stressing, the specimens were again examined with a stereoscopic microscope at 30 diameters magnification for surface flaws or cracks that might have occurred due to stressing. Specimens indicating surface flaws or cracks during pretest examination were discarded. After examination, specimen assemblies were degreased in acetone and handled with clean lint-free gloves to avoid further contamination.

Loading of Specimen Rack and Autoclave. Inspected specimens were located on the specimen support as shown in Figure 1 so that one-half of the specimens were immersed in the liquid phase and the other half in the vapor phase at the beginning of the test. Initial Phase 1 tests were conducted with 36 specimens located in each half of the autoclave. Later Phase 1 tests were performed with only 18 specimens in each half because statistical analysis indicated that adequate evaluation of test results could be obtained with the reduced number. A reduced number also was used in Phase 2 tests: 12 from each heat, A, B and C, distributed equally in the top and bottom half.

Before the specimen rack was placed in the autoclave, 12.5 liters of test solution were poured into the autoclave. This solution contained the specified water treating chemicals and inhibitor. When an oxygen scavenger was used in the solution to remove oxygen from the autoclave or when the autoclave was evacuated to remove oxygen from the vapor space above the solution, the procedure was altered by installing the specimen rack and the autoclave head first, followed by evacuating the autoclave with a vacuum pump. The test solution then was drawn into the autoclave under vacuum through the sample line.

Operation of Autoclave. Charged with test solution and U-bend specimens, the autoclave was heated to operating temperature. When the temperature reached 500 F, periodic tilting of the autoclave was begun. The tilt cycle consisted of holding the autoclave alternately in the upright position for five minutes and in the inverted position for five minutes. This cycle was repeated 144 times during the test period. After 24 hours at temperature, heating and tilting of the autoclave was stopped. Rapid cooling was accomplished by forced circulation of air over the external surfaces of the autoclave. When test solution temperature dropped to 185 F, the autoclave was opened and specimens removed for examination.

In Phase 2, autoclave operation was varied slightly in some tests to provide additional information on certain specific points of interest. Included among these variations was a tilt cycle change to coincide with the heating cycle. This variation permitted the specimens in the top half of the autoclave to be brought in contact with the test solution containing inhibitor from the start. This was considered to more nearly simulate boiler operating conditions and avoided exposure of the specimens to untreated condensate and oxygen before coming in contact with the inhibitor. Another variation included a 21-day test using the same set of specimens to evaluate the long term effectiveness of sodium nitrate.

Examination of Exposed Specimens. At the end of each test, specimens were thoroughly examined again under the 30-power microscope for stress corrosion cracks while still in the stressed condition. Distance between the ends of the stressed specimens again was measured by micrometer. The specimens were then unbolted and the resulting distance between the ends of the unstressed U-bend specimens was measured. These measurements provided evidence that the specimens had remained stressed beyond the yield point during test.

Metallographic Examination of Selected Specimens. Selected cracked and uncracked specimens from the top and bottom halves of the autoclave were given a thorough metallographic examination. This examination provided further evidence of the uniformity of structure of the steel, as well as evidence that cracks found by the microscope examination were actually stress corrosion cracks typical of those occurring in a chloride-oxygen environment. Representative specimens in which no cracks were found with the microscope were examined metallographically as further evidence that cracked specimens were not being overlooked by the first method of examination.

Test Results

Phase 1 Results

Results of Phase 1 screening tests are shown in Figures 4 through 8. Several control runs were performed during the Phase 1 tests to insure that a large number of specimens cracked in the absence of inhibitors. Control test results are shown in Figure 4. With the exception of the initial 500 ppm chloride control, a high percentage of the Type 347 U-bend specimens cracked in each control run indicating that the test procedure was valid for evaluating inhibitor performance.

Tests with oxygen scavengers are shown in Figure 5. The initial test with sulfite showed a high percentage of cracking in the vapor phase, believed to be associated with incomplete oxygen scavenging. On the other hand, with sulfite and oxygen concentrations at approximately the same levels as in the first test but with 50 ppm chloride concentration, complete protection was obtained. It was expected that hydrazine might afford good vapor phase inhibition because of its volatility. However, as shown in Figure 5, only partial protection against cracking was obtained in the vapor phase. The test with lignin plus sulfite plus sodium nitrate was run under identical conditions with the sulfite tests in 500 ppm chloride solution. Only one specimen cracked in the vapor phase and none in the liquid phase, indicating that this combination of inhibitors was superior to sulfite alone. The term vapor phase refers to specimens located initially in the top half of the autoclave, and liquid phase refers to specimens located initially in the bottom half.

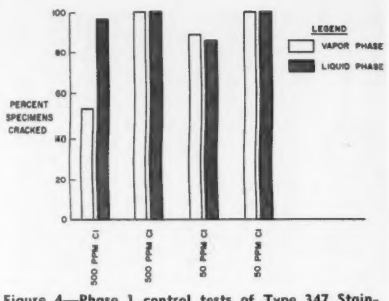

Figure 4—Phase 1 control tests of Type 347 Stainless steel U-bend specimen cracking rates.

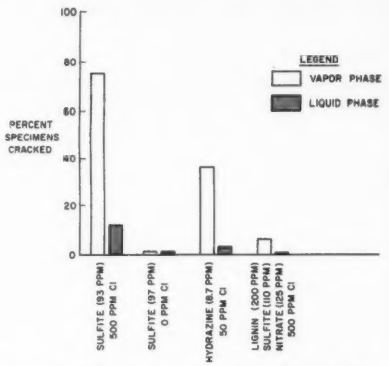

Figure 5—Phase 1 oxygen scavenger tests cracking rates.

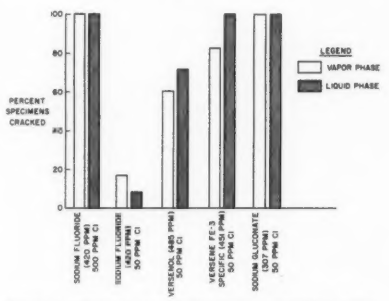

Figure 6—Phase 1 complexing agents cracking rates.

Results of tests with inhibitors classed as complexing agents are shown in Figure 6. As shown, sodium fluoride at a concentration of 420 ppm afforded satisfactory protection only in 50 ppm chloride solution. The other complexing agents tested afforded either inadequate or no protection.

Several film forming agents and organic inhibitors were tested; results are shown in Figure 7. The protection afforded against chloride stress corrosion was unsatisfactory in each case.

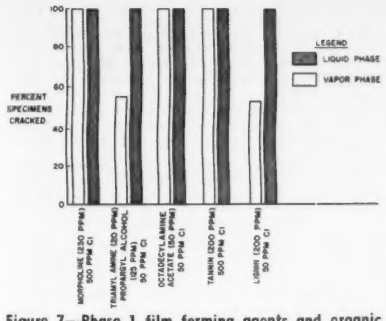
PERCENT SPECIMENS CRACKED
LEGEND
LIQUID PHASE
VAPOR PHASE
MORPHOLINE (250 PPM) 500 PPM Cl
TRIAMYL AMINE (80 PPM) ISOPROPYL ALCOHOL (100 PPM) 50 PPM Cl
OCTADECYLAMINE ACETATE (80 PPM) 50 PPM Cl
TANNIN (200 PPM) 500 PPM Cl
LIGNIN (200 PPM) 50 PPM Cl

Figure 7—Phase 1 film forming agents and organic inhibitors cracking rates of Type 347 stainless U-bend specimens.

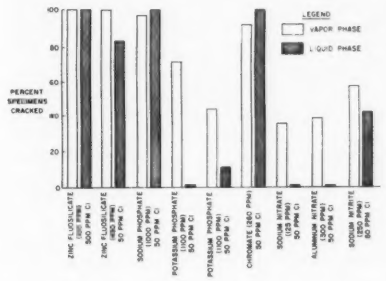
PERCENT SPECIMENS CRACKED
LEGEND
VAPOR PHASE
LIQUID PHASE
ZINC FLUOSILICATE (1000 PPM) 500 PPM Cl
ZINC FLUOSILICATE (480 PPM) 50 PPM Cl
SODIUM PHOSPHATE (1000 PPM) 50 PPM Cl
POTASSIUM PHOSPHATE (1100 PPM) 50 PPM Cl
POTASSIUM PHOSPHATE (1100 PPM) 50 PPM Cl
CHROMATE (280 PPM) 50 PPM Cl
SODIUM NITRATE (140 PPM) 50 PPM Cl
ALUMINUM NITRATE (300 PPM) 50 PPM Cl
SODIUM NITRITE (140 PPM) 50 PPM Cl

Figure 8—Phase 1 inorganic inhibitors used to obtain cracking rates of Type 347 stainless steel U-bend specimens.

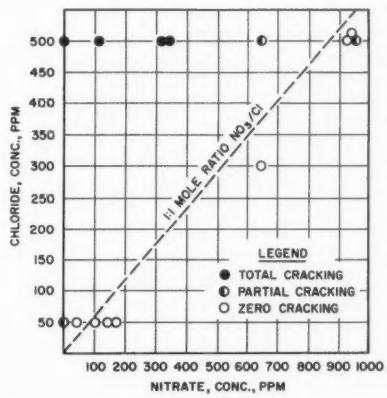

Figure 9—Phase 2 test on dependency of nitrate inhibition on nitrate concentration at various chloride levels.

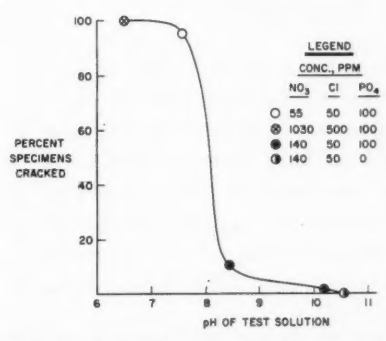

Figure 10—Phase 2 nitrate tests on dependence of nitrate effectiveness on pH.

Figure 8 shows test results with inorganic inhibitors. The cracking rate observed with the combination of potassium phosphate and potassium hydroxide was considered low enough to warrant further investigation in Phase 2 although the amount of cracking obtained on vapor phase specimens was undesirably high. In two tests with nitrate—one with nitrate added as the sodium salt and the other using the aluminum salt, only 40 percent of the vapor phase specimens cracked and none of the liquid phase specimens. It was considered that nitrate should be investigated further in Phase 2. In a single test with sodium nitrite, an undesirably high cracking rate was obtained.

Two inhibitors were selected for further investigation in the Phase 2 tests: sodium sulfite and sodium nitrate. In addition, three inhibitor combinations were selected for investigation: sodium sulfite plus sodium nitrate, potassium phosphate plus potassium hydroxide and potassium phosphate plus potassium hydroxide plus potassium nitrate.

Sodium fluoride, which appeared promising from data in Phase 1 tests, was discarded because of practical problems associated with its application to operating steam generators.

Phase 2 Results

Bulk of the Phase 2 program was devoted to investigation of the effectiveness of nitrate in protecting against chloride stress corrosion attack. A series of tests were conducted to determine the concentration dependence of nitrate and chloride. Test results are shown in Figure 9. For chloride concentrations of 50 and 500 ppm, the minimum nitrate concentrations required to give complete protection were 50 and 1000 ppm respectively.

During Phase 2 tests, it was discovered that the effectiveness of nitrate is pH dependent. These test results are shown in Figure 10.

The combination of potassium phosphate, potassium hydroxide and potassium nitrate was also investigated. Results appeared identical to those for sodium nitrate as shown in Figure 9. These tests were conducted with a phosphate concentration of 300 ppm added as potassium mono-hydrogen phosphate (K_2HPO_4), and pH adjusted with potassium hydroxide. The reduced phosphate level was tested because of practical problems associated with use of the high concentration (1100 ppm PO_4) required, based on the Phase 1 test (See Figure 8), to prevent stress corrosion cracking.

A single test was performed with the combination of sodium nitrate (150 ppm) plus sodium sulfite (65 ppm residual) at the 500 ppm chloride level, and no cracking of the Type 347 specimens was detected. In tests with sodium nitrate alone (See Figure 9) or sodium sulfite (See Figure 5) under identical conditions of chloride and oxygen concentration, only partial protection had been obtained. Apparently, the combination of sulfite and nitrate is superior to either sulfite or nitrate alone.

A test considered significant was conducted in which oxygen was excluded from the test solution and autoclave as completely as possible, chloride concentration was 500 ppm and no inhibitor was employed. None of the Type 347 stainless U-bend specimens had cracked at the conclusion of the 24-hour test. Cracking typical of that observed in other control runs conducted at 500 ppm chloride concentration with oxygen added is shown in Figure 3.

Phase 3 Results

As a prelude to Phase 3 model boiler tests with sodium nitrate (140 ppm as NO_3), a test was conducted in which U-bend specimens were exposed for 21 days in the tilting autoclave to a solution containing 50 ppm chloride, high oxygen, 300 ppm phosphate and pH 11.0. Specimens were removed from the autoclave for daily examination during the first 11 days and every other day thereafter. This removal, of course, required a daily heat-up and cool-down of the autoclave. At the conclusion of the test, none of the 36 specimens remaining in the autoclave had cracked, nor were cracks found on any of the specimens removed prior to the end of the test.

Conclusions

Based on Phases 1 and 2 tests results, the following conclusions are made:

1. Sodium nitrate appears to inhibit chloride stress corrosion attack of Type 347 stainless steel in tilting autoclave tests if the mole ratio of nitrate to chloride used is at least unity and the pH of the solution containing chloride is higher than about 10.5.
2. Chloride stress corrosion attack of austenitic stainless steel can be prevented, at least in tilting autoclave tests, by exclusion of oxygen. If properly applied, sodium sulfite can be employed as the oxygen scavenging agent.
3. Combination of sulfite and nitrate appears superior to either inhibitor alone at least under the conditions of the tilting autoclave test.
4. Sodium nitrate and sodium sulfite should be investigated further in model boiler tests for application in prevention of chloride stress corrosion attack in austenitic stainless steel tubed steam generators.

Although the work reported in this article is limited to Phases 1 and 2 of the inhibitor program, it is considered important to report that in three, shell-and-tube model boiler tests (Phase 3) with sodium nitrate, cracking has been found on Type 347 stainless tubing in all boilers in the tube-to-tube sheet crevice area. The apparent discrepancy between model boiler test results and tilting autoclave test results with nitrate has not been resolved. Additional model boiler tests are now in progress or contemplated to investigate sodium sulfite and the combination of sodium sulfite and sodium nitrate.

Acknowledgment

The authors wish to acknowledge the assistance of the following Westinghouse and National Aluminate Corporation personnel who contributed to the pro-

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Metallurgical examinations and evaluation were performed by E. G. Johnson of the National Aluminate Corporation. Autoclave and test operation were supervised by R. A. Berner of the National Aluminate Corporation. Statistical design of the program and evaluation of results were done by W. H. Clatworthy and A. C. Nelson of Bettis Plant. Bureau of Ships personnel T. J. Iltis, F. R. Standerfer and E. J. Wagner also contributed to the design and evaluation of the program.

References

1. H. R. Copson. Influence of Corrosion on the Cracking of Pressure Vessels. *Welding J*, 32, 755 (1953).
2. C. Edeleanu and P. P. Snowden. Stress Corrosion of Austenitic Stainless Steels in Steam and Hot Water Systems. *J Iron and Steel Inst.*, 186, Part 4, 406-422 (1957) August.
3. D. J. DePaul. Corrosion and Wear Handbook for Water Cooled Reactors. U. S. Atomic Energy Commission, Division of Reactor Development, Naval Reactors Branch, p. 187 (1957) March.
4. W. L. Williams and J. F. Eckel. Stress Corrosion of Austenitic Stainless Steels in High Temperature Waters. *J Am Soc Naval Engineers*, 68, 93 (1954).
5. W. L. Williams. Chloride and Caustic Stress Corrosion of Austenitic Stainless Steel in Hot Water and Steam. *Corrosion*, 13, 539t (1957) August.

Any discussion of this article not published above will appear in the December, 1959 issue

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Factors Influencing Corrosion*

By G. V. AKIMOV

Abstract

External and internal factors influencing the rate and distribution of corrosion are discussed. Among the external factors considered are: pH of the solution, influence of elements acting as inhibitors or as stimulants of corrosion, the concentration of neutral salts, the temperature of solution and the rate of solution movement. Corrosion damage caused by stray electric currents is described in detail and measures eliminating or minimizing their effect are suggested.

Internal factors considered include the inherent chemical properties of elements (that is, their position in periodic table). However, a distinction is made between chemical and corrosion stability, because of the possibile formation of protective films. Furthermore, the influence of internal stresses as well as of alternating stresses in metals in corrosive media (corrosion fatigue) is described. Surface conditions influencing corrosion are mentioned. Stability of monophasic and of heterophasic alloys and the influence of grain size on corrosion are discussed. Finally, experimental data on stability limits of solid solutions and related phenomena such as dezincification are given and some attempts at the explanation of stability limits of solid solutions are mentioned. 3.8.4

Introduction

THE CORROSION process depends on a large number of factors which for the most part do not act independently of each other. Instead there is a complex mutual interaction of the factors.

Factors which determine the rate and distribution of corrosion can be divided in two large groups: (1) external and (2) internal.

External factors are those connected with the conditions of corrosion (i.e., with the nature of the medium—its chemical composition and the presence in the solution of substances retarding or accelerating the corrosion process). Furthermore, among the external factors we consider motion of the electrolyte relative to the metal, the temperature and the pressure. There are also other less important factors such as the action of light.

Internal factors of corrosion are those connected with the metal itself. The most important internal factor is the chemical nature and the structure of the metal.

Next in importance among the internal factors are the internal stresses and deformations in metals and the surface condition. Finally, in this connection we shall consider a special type of corrosion —corrosion fatigue. This phenomenon is connected with the simultaneous action on metal of both the corrosion and the mechanical factors (alternating stresses).

External Factors

Influence of pH on the Rate of Corrosion

The most important external factor is, of course, the chemical nature of the electrolyte in which the metal is corroding. A very general and, at the same time, an extremely important characteristic of the electrolyte is the value of pH of the electrolyte solution. Therefore, consideration of the influence of the nature of the electrolyte upon the rate and distribtuion of corrosion will start with the dependence of corrosion rate upon pH of the solution. We shall first consider the case when the solution in itself is not an oxidizer, and it contains only the oxygen of the air which is almost always unavoidable.

Several typical diagrams can be constructed, demonstrating the dependence of the rate of corrosion on pH of the solution (Figure 159).

The first and the most simple diagram of corrosion vs. pH of the solution, is the diagram for the noble metals gold and platinum (Figure 159 I). The functional dependence of the rate of corrosion on pH of the solution is represented for these metals by a straight line located in the diagram somewhere close to the bottom. In other words, the diagram shows that the rate of corrosion is extremely low and actually depends very little on pH of the solution. For very high values of pH of the solution, one can observe a slight rise of the curve; in other words, there is some perceptible increase of corrosion. However, this rise has little practical significance.

The second type of pH-corrosion diagram belongs to such technically important metals as zinc, aluminum and lead (Figure 159 II). As the diagram shows, there is for these metals a sharp increase of the corrosion rate, both in acid and in basic solutions as compared with neutral solutions. Each metal has, of course, its own absolute rate of corrosion and a characteristic curve, but the general form of the curve is the same for a number of metals. This shape of the curve becomes plausible when one takes into consideration that the oxides of the abovementioned metals are soluble both in acid and in alkaline solutions. Zinc oxide, ZnO, dissolves in acid solution with the formation of salts, and in the basic solutions with the formation of complex compounds—zincates of Na_2ZnO_2. Thus, the metal loses the protective film both in acids and in bases, and this explains the rapid increase of the rate of corrosion in the left and in the right side of the diagram. The curve rises much steeper in the acid range than in the basic range. On the other hand, the oxides of aluminum are more stable in the acid range than in the basic range because aluminum easily forms complex aluminate compounds Na_3AlO_3 with the alkalies. Accordingly, the aluminum curve has a steeper rise in the basic range and a slower rise in the acid range.

Figures 160 and 161 depict diagrams of this type for Zn and Pb. Finally, let us consider a third type of pH-corrosion diagram that also belongs to a fairly large number of practically important metals, such as Fe, Ni, Cd, Mg (Figure 159 III). These metals do not form soluble complex compounds in the basic range, and therefore the protective film on these metals not only does not dissolve, but becomes more stable because of the decrease of its solubility.

Figure 162 depicts the dependence of solubility of ferrous hydroxide upon pH of the solution. With increased pH, the solubility of $Fe(OH)_2$ decreases, so that the rate of corrosion of iron in the higher pH range also decreases. In the acid range, there is a similar increase of the rate of corrosion as in the diagrams of the second type (Figure 163).

For some metals, particularly for iron, the pH-corrosion diagram could be extended into the range of very high pH values (> 14). In this range, the corrosion of iron at elevated temperatures (of

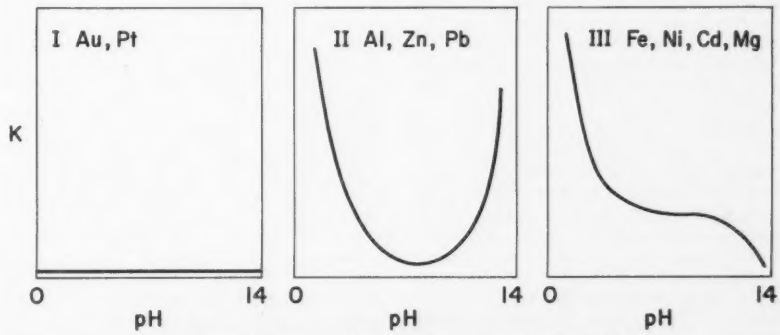

Figure 159—Diagrams showing corrosion vs pH (Akimov).

★Chapter 5 of the book "Theory and Research Methods of Metallic Corrosion" published originally by the Publishing House of the Academy of Science, U.S.S.R., Moscow, 1945. This translation was prepared by S. S. Levy and R. B. Mears, both of the Applied Research Laboratory, U. S. Steel Corporation.

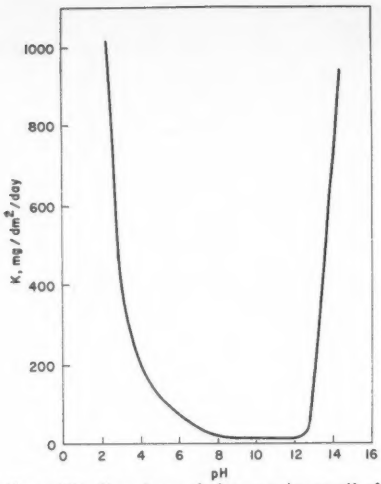

Figure 160—Dependence of zinc corrosion on pH of the solution (Roetheli, Cox and Littreal).

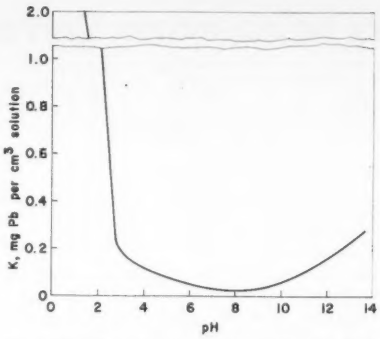

Figure 161—Dependence of lead corrosion on pH of the solution (Anderegg and Echatz).

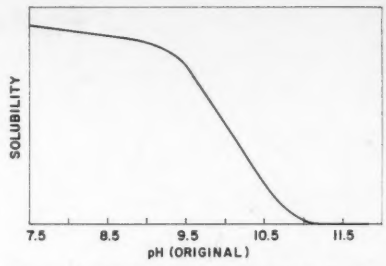

Figure 162—Solubility of ferrous hydroxide in solutions of NaOH (Whitman, Russell and Davis).

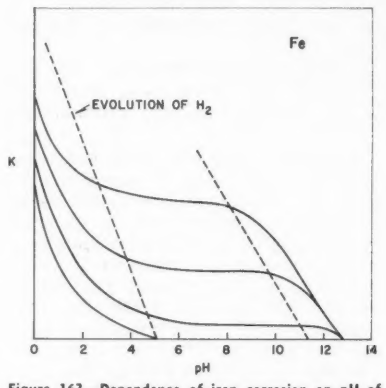

Figure 163—Dependence of iron corrosion on pH of the solution (Wilson).

the order of 80—120 C) is increasing. Thus, in the case of iron we apparently approach, for very high pH values, the second type of the diagram, with the only difference that the horizontal part of the curve is longer. The increase of iron corrosion is due to the fact that at very high concentrations of base and at high temperatures, iron can form complex compounds, the so-called ferrates. It is well known that iron in concentrated bases is subject to an intense intercrystalline corrosion. Apparently, this phenomenon is also connected with the formation of ferrates; the potential at the grain boundaries is lowered to the extent that corrosion of iron with hydrogen evolution becomes possible.

The relationships so far considered correspond to cases when the solutions by themselves are not oxidizers and contain only dissolved oxygen. Many cases are known, however, in which the solution itself has oxidizing properties, for instance, the solutions HNO_3, CH_3COOH, H_2SO_4 in high concentrations. The dependence of the rate of corrosion upon pH is made more complicated in these cases by the presence of oxidizers.

For instance, the rate of iron corrosion in sulfuric acid first increases with the acid concentration, but after a certain concentration is reached, the rate of corrosion drops to zero.

This is due to the fact that with the increasing H_2SO_4 concentration not only does the hydrogen ion concentration increase, but also the oxidizing properties of the sulfuric acid solution. After a certain (high) concentration is reached, when the oxidizing properties of the solution become considerable, iron is passivated (Chapter 6).

In the case of a solution that is an even stronger oxidizer than sulfuric acid, the situation is similar but the curve bends downward at lower concentrations.

A similar curve may be obtained not only in cases when the medium has oxidizing properties, but also when a stable protective film is formed on the metal at a high concentration of the active reagent. A good example is the action of sulfuric acid on lead. In this case also, the rate of corrosion is small over a wide range of sulfuric acid concentration because of the formation of a protective film of lead sulfate.

Action of Inhibitors in Solution[2,4]

Let us now consider the action of another external factor, namely, oxygen in the solution. This factor is of great importance and plays a large part in corrosion processes.

The influence of oxygen in the solution should be considered from two viewpoints that are opposite to each other, with respect to the rate of corrosion. First of all, it is well known that oxygen is a good depolarizer. Hence, the presence of oxygen should increase the rate of the cathodic process, and when the latter is the controlling factor, the rate of the corrosion process, of course, will be increased also. At the same time, oxygen increases the stability of the protective oxide films on many metals.

We already know that increase of oxygen concentration in the solution usually increases the electrode potential of the majority of metals, including such technical important ones as iron. We also know that an oxidizer is often necessary for the formation of a stable protective film. It is evident that the higher the oxygen concentration in the solution, the greater the probability for the formation of such protective films. If the protective film was formed when the metal was still exposed to the air and it has some weak points where the corrosion process can start, then the larger the amount of oxidizer in the solution, the easier such weak spots will be closed up by the forming oxides.

It is therefore necessary to consider the dual influence exercised by oxygen in the process of corrosion. On one hand, oxygen might accelerate the corrosion process as a depolarizer, and on the other hand, oxygen might slow down the corrosion process because it improves the protective films.

In dealing with these questions, we encounter the concept of "probability of corrosion." Let us assume that under given conditions, four spots will be found on a (iron) plate indicating the commencement of corrosion ("corrosion centers"). Let us further assume that under different conditions on an identical piece of iron, 20 corrosion centers will be found. This is expressed by saying that the probability of corrosion was in the first case five times smaller than in the second. However, this does not mean at all that the rate of corrosion in the second sample is also five times greater than in the first sample. Investigations conducted in the past few years demonstrated that, generally speaking, the smaller the probability of corrosion, the greater the corrosion rate in the affected spot (i.e., the corrosion process, if it will start at all, will be the more intense, the fewer are the corrosion centers). Thus we can expect, in our example of iron samples, that the rate of disintegration in each particular corrosion point will be larger in the first sample than in the second, although the probability of corrosion for the second sample is considerably higher than in the first. This statement, however, is only approximately true.

In considering the dual influence of oxygen, we can say therefore that oxygen lowers the probability of corrosion, diminishes the number of center where the corrosion process may commence (i.e., the number of the nuclei of corrosion), but at the same time increases the corrosion rate in the points where the corrosion process already started—in each corrosion center.

Substances accelerating the corrosion rate are often called corrosion stimulants. Those retarding the corrosion rate are called inhibitors.

We may say that oxygen is at once a stimulant and an inhibitor of corrosion. It is a stimulant in the sense that it is a powerful depolarizer, which increases the rate of the corrosion process by accelerating the cathodic process, and at the same time it is an inhibitor when it

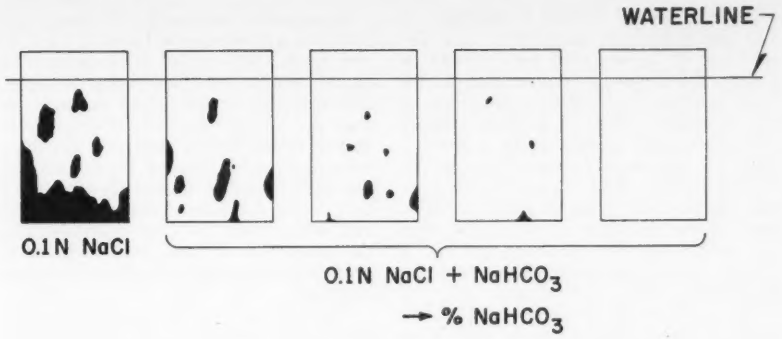

Figure 164—Corrosion distribution in iron samples in 0.1 N NaCl solution with varying amount of $NaHCO_3$ (Evans).

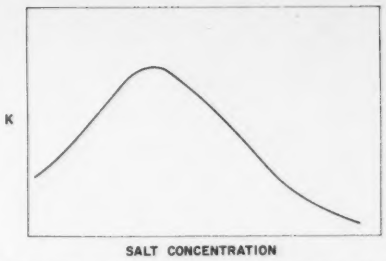

Figure 165—A typical dependence of corrosion rate upon the concentration of salt in the solution.

improves the stability of the protective film.

It can be expected therefore that at low and medium concentrations of oxygen in the solution, it usually increases the corrosion rate, although it somewhat reduces the probability of corrosion. Diminishing the corrosion probability is by no means an advantage; from a practical point of view it is a drawback, because, while there are fewer corrosion centers, the destruction in them proceeds faster than in the case of a larger area which is subject to corrosion. The corrosion centers disappear only when the oxygen concentration is sufficiently high, so that the corrosion probability is zero (i.e., the metal becomes completely passive, under the given conditions.) At lower oxygen concentrations, before complete passivity is reached, oxygen makes matters worse not only by increasing the general rate of the corrosion process, but also by concentrating the intense corrosion destruction on a few spots.

The action of oxygen as a corrosion stimulant is the more pronounced, the lower pH value of the solution. This is due to the fact that the protective films on many metals are less stable in acid solutions. In basic solutions, the inhibitive properties of oxygen, for such metals as iron and nickel, is very pronounced, and even a small amount of oxygen is often sufficient to stop the corrosion process completely.

Copper, in contrast to iron, has a fairly high chemical stability. At the same time, the protective films on copper are not formed easily under the action of oxygen and they do not have the high protective qualities as those on iron. Therefore, for metals such as copper, oxygen is mainly a stimulant, and not an inhibitor. The experimental data actually show that the concentration of oxygen and other oxidizers in the solution often determines the rate of copper corrosion. The destruction of copper proceeds extremely slowly even in fairly acid solutions, in the absence of oxidizers. However, in the presence in the solution of oxidizers such as oxygen of the air or nitric acid, copper corrodes fairly fast, the rate being the greater the higher the concentration of the oxidizer in the solution. An example of this kind is given below.

H_2SO_4 Concentration, %	Corrosion Rate, mg/dm² per day	
	Oxygen	Hydrogen
6	920	22
20	840	36
96.5	250	35

It can be seen from the above tabulation that the rate of corrosion is several times greater when the atmosphere above the sulfuric acid solution is oxygen as compared with a hydrogen atmosphere.

Thus, in evaluating the dual influence of oxygen as a stimulant and as an inhibitor, we must consider the properties of the metal. The inhibiting influence of oxygen on iron is much stronger than on copper. Aluminum is similar to iron in this respect.

Oxygen is not the only substance acting as an inhibitor and at the same time as a stimulant. There are a number of compounds which behave similarly in solution.

In the case of iron corrosion, the influence of additions of sodium bicarbonate ($NaHCO_3$) and of acid sodium phosphate (Na_2HPO_4) was studied in detail. Relatively small amounts of these substances also lower the probability of corrosion, but they accelerate the corrosion in the spots where the corrosion did comence (corrosion centers). Both the rate and the probability of corrosion can be reduced to zero by raising the concentration of these compounds to a certain level.

The distribution of corrosion for an iron sample in 0.1 N NaCl solution with varying additions of $NaHCO_3$ is depicted in Figure 164. It can be seen that by introduction of $NaHCO_3$ the total area attacked by corrosion decreases rapidly. However, measurements show that the intensity (of corrosion) on each attacked spot sharply increases. Complete protection is achieved only after the introduction of a considerable amount of bicarbonate.

It is of great importance whether the metal sample is completely or only partially immersed in the solution.

In practice, one often encounters the presence of a water line (sea or river vessels, gasholders, cooling systems, etc.).

In the case of a sample of ordinary iron half-immersed in the solution of NaCl, the corrosion distribution is as depicted in Figure 164. The water line is barely touched by corrosion. This is due to the abundant supply of oxygen creating a differential aeration cell in which the water line and the middle part of the sample form the cathode, whereas the lower end and the sides of the sample become anodic, and corrode.

However, when an inhibitor is present in an amount insufficient for complete protection, the opposite is observed: the corrosion may appear at the water line. This occurs because under these conditions, separation into cathodic and anodic sections, as a result of differential aeration, is not as effective.

The chromates of the alkali metals (i.e., $K_2Cr_2O_7$ and $Na_2Cr_2O_7$), efficiently reduce the rate of the corrosion process. The chromates can be called universal passivators, because these compounds are inhibitors. The introduction of even a small amount of a chromate into a neutral solution is sufficient to stop the corrosion completely. However, also for this class of inhibitor the rule, which we have established for oxygen, is applicable (i.e., with an insufficient amount of a chromate, the corrosion will be of a more dangerous kind than in its complete absence because the corrosion will concentrate on a small number of points which will be attacked very rapidly).

The amount of a chromate that is usually sufficient for complete supression of corrosion of iron, zinc and copper, is of the order of a tenth or a hundredth of one percent. It depends greatly, however, on the presence in the solution of other substances (particularly chlorides) that activate corrosion.

With an increase in the concentration of hydrogen ions, the inhibiting action of the chromates decreases, and in a sufficiently acid solution, chromates may even considerably increase corrosion because being oxidizers, they also strongly depolarize. Thus, only in neutral, basic or very weak acid solutions can the chromates be utilized as inhibitors.

One would be inclined to think, because of the marked influence of the chromates on the corrosion of iron, zinc and copper, that the strong oxidizers such as permanganates, vanadates and hydrogen peroxide, would also exert energetic passivating influence. It turns out,

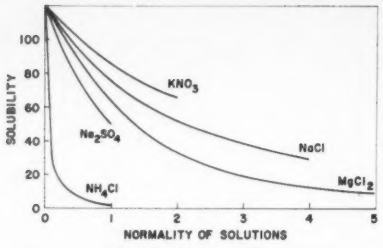

Figure 166—Solubility of oxygen as a function of salt concentration in solution at 25 C. Solubility in pure water is 100 (Speller).

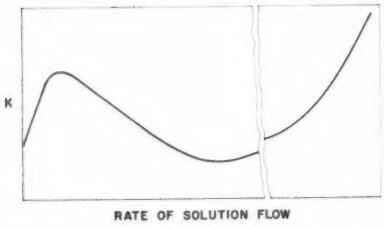

Figure 167—Dependence of the corrosion rate upon the rate of the solution flow.

however, that these substances reduce corrosion considerably less, and they have to be introduced into the solution in much larger amounts in order to reduce the corrosion rate to zero.

All of the inhibitors so far discussed (i.e., oxygen, sodium bicarbonate and chromates), are called anodic inhibitors. This is because they reduce the anodic area. There are, however, cathodic inhibitors which lower the corrosion rate by reducing the cathodic area. The reduction of the cathodic area is accomplished by the formation of insoluble compounds, which weaken the action of the cathodes.

Among the cathodic inhibitors are $Ca(HCO_3)_2$, $ZnSO_4$, some nickel compounds and a number of magnesium compounds. In the presence of these substances in the solution, insoluble compounds might be formed that cover the cathodic areas and isolate the cathode from the solution (i.e., the cathodic area is reduced).

The cathodic inhibitors belong to the class of safe inhibitors. Whether they are present in larger or smaller amounts in the solution, there is always a reduction of corrosion. The decrease of the corrosion rate might be insufficient from a practical viewpoint, but at any rate the introduction of such inhibitors would not intensify the corrosion in some of the areas, as is observed in the case of an insufficient amount of an anodic inhibitor.

The third group of inhibitors consists of some organic colloids. These inhibitors are efficient mainly in acid solutions. To this group belong gelatine, agar-agar, sulfonated glue, derivatives of quinoline, many alkaloids and others. It is characteristic of these inhibitors that they exert a strong protective influence when introduced into the solution in small amounts, usually about hundredths and tenths of one percent.

The theory of colloidal inhibitors is not yet sufficiently developed, but the majority of investigators are inclined to accept the following explanation. In an acid solution the colloidal particles of the inhibitor carry a positive charge. Therefore, they move in the (electric) field of the microelements toward the cathodic areas. After being absorbed at the microcathodes, the colloidal particles increase the hydrogen overvoltage to such an extent that the discharge hydrogen cannot proceed anymore. Thus, the destruction of the metal ceases.

The colloidal inhibitors are widely used in the acid pickling of metals to remove scale from the metal. The problem here is to dissolve the scale without destroying the metal. This is achieved by adding the inhibitor to the acid solution.

Since the colloidal particles of organic inhibitors in basic solutions carry a negative charge, these compounds cannot be expected to act as inhibitors in basic solutions. As a matter of fact, very rarely can an organic inhibitor be found that is efficient in both neutral and basic solutions. There are cases, though, when one can select inhibitors having a noticeable influence in neutral solutions as well as in pure water. For instance, 0.2 percent of agar-agar in pure water reduces the corrosion rate of iron to 2.7 percent of the initial value, that of lead—to 1.4 percent, and that of zinc to zero.

Action of Stimulants in Solutions

In the preceding section we have considered substances that retard corrosion. It was already mentioned that a very important inhibitor—oxygen—also acts as a stimulant and that the influence of oxygen depends on its concentration in the solution and on external conditions. In evaluating the role of the medium, one has to consider also the presence of substances which are definitely stimulants. These include, first of all, the so-called oxygen transmitters.

Let us assume that there are ferric salts in the solution in which iron is corroding. These salts are good depolarizers because they can change into a ferrous form and consequently will accelerate corrosion. Because the solution is in contact with air, additional oxygen will enter into the solution. The ferrous salts that are formed as a result of the depolarization reaction, under the action of dissolved oxygen, will again become ferric salts. The latter will be again reduced at the cathode to a ferrous form, then again oxidized, and so forth. Thus, the presence of ferric salts will considerably accelerate the process because the ferric salts are oxygen transmitters.

Cupric salts act similarly in the corrosion of copper. The so-called complex formers are very energetic stimulants. Ions may be present in the solution which can form complex ions with the metal ions. This lowers the concentration of metal ions and thus lowers the electrode potential of the metal.

Among the complex forming stimulants are the cyanides which, in the presence of oxygen, greatly accelerate the destruction of even such metals as silver and gold.

Ammonium compounds and ammonium solutions are extremely harmful for copper. In the presence of these compounds in the solution, complex copper ammoniates may be formed which strongly reduce the concentration of the copper ions at the metal surface and thus facilitate its corrosion. It should be emphasized that these complex compounds are formed only in the presence of oxygen. Ammonia and ammonium salts by themselves, in the absence of oxygen, are incapable of greatly accelerating the process of copper corrosion.

Ions also may be present in the solution which cause precipitation of the metal ions as insoluble sediments. In that case, the inhibiting action may not occur unless the insoluble compounds are formed on the surface of the metal. Then the presence of ions of this kind lowers the concentration of metallic ions at the metal surface.

Some of the hard insoluble compounds which are precipitating at the metal surface, have sometimes such poor protective qualities that the corrosion is greatly accelerated in the presence of ions causing this precipitation. Sulfides are the foremost representatives of this group. The sulfides of copper and iron have very low protective properties, and, as a rule, when sulfides are formed, the corrosion of copper and iron is accelerated. This phenomenon is connected with lowering of the concentration of the metal ions at the metal surface.

Influence of Concentration of Neutral Salts

Exact measurements have demonstrated that in many cases the dependence of the corrosion rate upon the concentration of a neutral salt is represented by a curve having a maximum (Figure 165). The maximum is located at different values of the concentration for different metals and salts.

The ascending branch of the curve is connected with an increase of the electroconductivity of the solution with the increase of concentration, therefore, the magnitude of the corrosion current may increase. Moreover, we know that the increase of concentration of anions such as Cl^-, SO_4^{--}, reduces the protective properties of the films and thus enhances the corosion rate. However, with the increase of concentration of salt in the electrolyte the solubility of oxygen drops (Figure 166), the rate of depolarization is decreased and accordingly the corrosion rate must decrease. Thus, when the salt concentration reaches a certain value, it can be expected that the oxygen deficiency in the solution is considerable. This explains the curve having a maximum. The descending branch of the curve indicates that concentrations are reached where the influence of oxygen deficiency prevails over the influence of the increase of electroconductivity of the solution and of the lowering of the protective qualities of the films.

Influence of Rate of Solution Movement

We turn now to the consideration of the next factor, namely, the influence of the rate of solution movement. The situ-

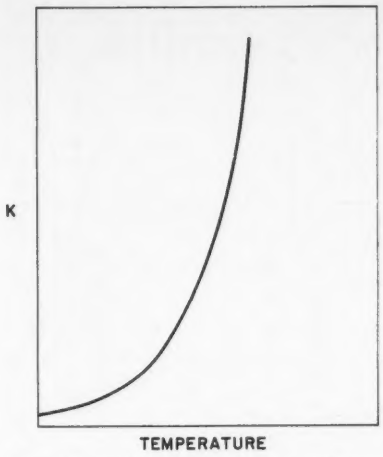

Figure 168—Functional dependence of corrosion rate upon temperature.

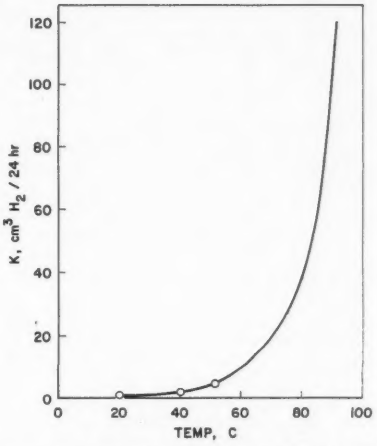

Figure 169—Dependence of corrosion rate of zinc in tap water upon temperature (Baylis).

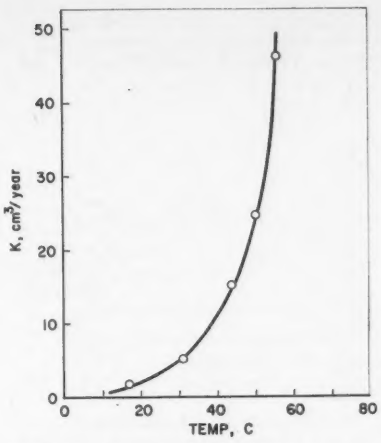

Figure 170—Dependence upon temperature of corrosion rate of iron in an 18 percent solution of HCl (Conroy).

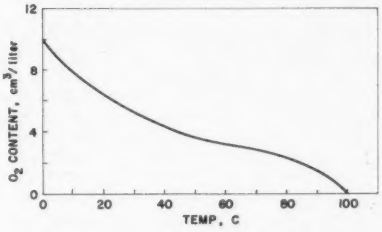

Figure 171—Solubility of oxygen in water at 760 mm pressure as a function of temperature.

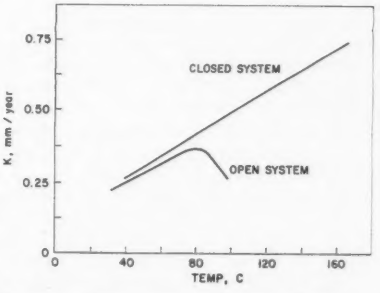

Figure 172—Dependence of the rate of iron corrosion in water upon temperature in a closed system and in an open system (Speller).

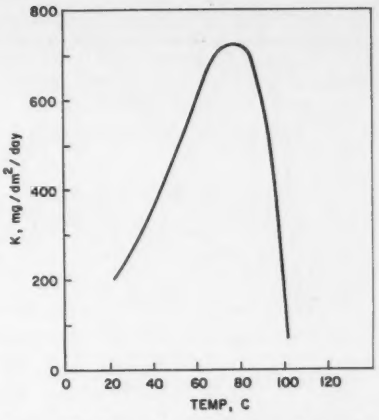

Figure 173—Temperature dependence of corrosion rate of Monel metal in 6 percent sulfuric acid saturated with air (McKay and Worthington).

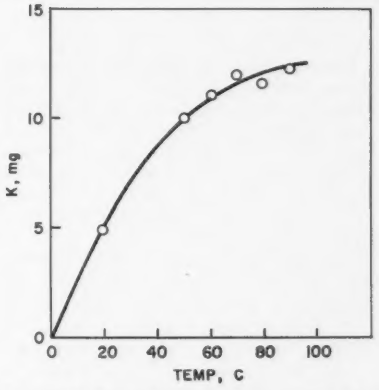

Figure 174—Temperature dependence of corrosion rate of copper in a 10 percent solution of NaCl (Reich and Colb). Time was 2 hours.

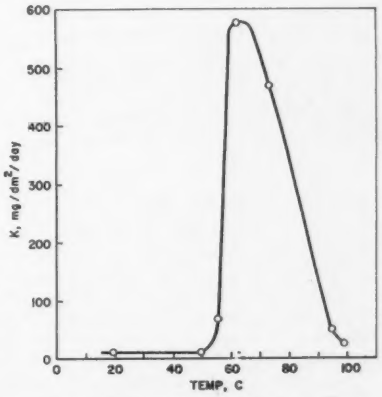

Figure 175—Temperature dependence of corrosion rate of zinc in distilled water (Cox).

ation here is quite complex because the increase of the rate of the solution movement often leads to changes of other factors; the interconnection of various factors is such that it is difficult to discern the influence of the solution movement by itself.

The most common dependence of corrosion of iron in neutral solutions upon the rate of movement is depicted in Figure 167. The corrosion rate first increases, then drops and finally, at a very high speed, increases again very rapidly. The explanation for the first part of the curve is relatively simple. In neutral solutions in the presence of oxygen from the air, the corrosion proceeds with oxygen depolarization. It is clear therefore that an increase in the rate of solution movement would increase the oxygen supply, and thus increase the depolarization. It is more difficult to explain the decrease of the curve that occurs with further increase in the rate of solution movement. There are several possible explanations. The most probable one, perhaps, is the passivation of iron because of the abundant oxygen supply. In other words, when the oxygen delivery is very abundant, its inhibiting propertties prevail over the stimulating ones. However, conditions are also possible when the drop in corrosion rate is not observed, but there is a continuous increase of corrosion with the increased rate of solution movement. This happens, for instance, in corrosion of pipes at a steady flow of solution.

In an acid medium the effect of the rate of solution movement is considerably less noticeable than in neutral solutions. It was proven in many cases of iron corrosion that an increase in the flow rate has only a weak influence on the corrosion rate.

Figure 167 shows that above certain values of the rate of the solution flow, corrosion increases rapidly. This is due to the fact that corrosion acquires special features, when the rate of solution flow becomes large—the so-called impingement corrosion. The high rate of corrosion is caused by the solution stream, flowing rapidly at the metal surface, tearing off the protective films that are formed on them during the corrosion process, or those that were present on the metal before corrosion started. At a very high rate of solution flow the metal actually corrodes without a protective film.

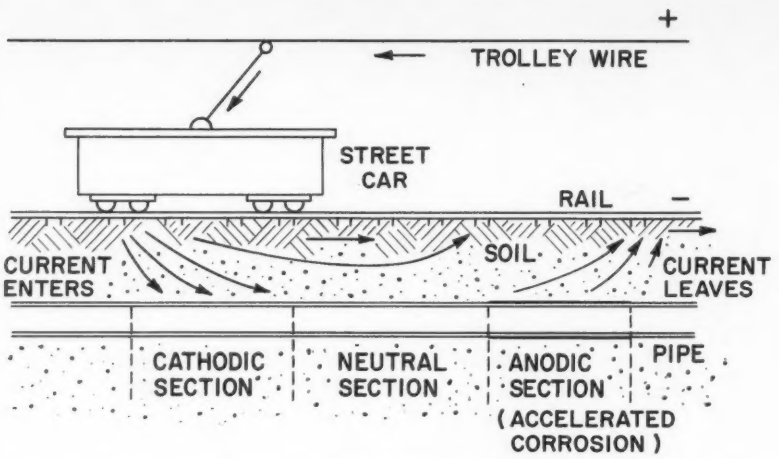

Figure 176—Diagram of current branching off from street car rail through a pipe in the ground and formation of cathodic and anodic sections (Akimov).

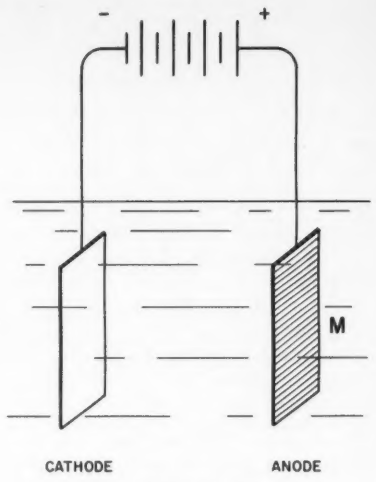

Figure 177—Anodic corrosion of the Sample M.

An example of impingement corrosion is the corrosion of brass condenser tubes through which large amounts of water are flowing with high velocity. Impingement results at places where the velocity changes rapidly, and a local impingement corrosion commences caused by surface disturbance of the protective film on the brass condenser tube.

Interesting phenomena are observed at still higher velocities. Instrumental here is not only the increase of water velocity, but also the so-called cavitation (formation of bubbles or empty spaces inside of a fast flowing liquid which results in an impact action). Destruction connected with cavitation is observed on parts such as steamship (screw) propellers of modern naval vessels, vanes of hydraulic turbines. The destruction of a propeller by cavitation commences very rapidly, sometimes after a few hours of operation and appears to consist of local chipping off of metal particles. Recent investigations show that purely mechanical factors are mainly responsible in cavitation destruction, and the influence of electrochemical factors is small.

Influence of Temperature

From considerations of chemical kinetics, one may expect that the rate of corrosion, as that of any other chemical process, must increase with rising temperature. Indeed, a steep increase of corrosion rate is observed for a very large number of corrosion processes, usually represented by an exponential curve (Figure 168). The dependence of the corrosion rate of zinc in an acid or in the tap water (Figure 169) and of iron in an acid (Figure 170) upon temperature belongs to this type.

However, in the field of corrosion one encounters not only the simple dependence of corrosion rate upon temperature that is given by the exponential curve. In a number of cases, the change of temperature modifies the influence of other corrosion factors. For instance, when corrosion proceeds with oxygen depolarization, one has to take into consideration that the increase of temperature acts in two different ways. On one hand, the increase of temperature accelerates the reaction rate in the usual way, and also enhances the convection currents and diffusion. On the other hand, the increase of temperature decreases the solubility of oxygen from the air (Figure 171) and, therefore, the concentration of oxygen in the solution drops with increasing temperature. It can be expected, therefore, that increase of temperature will first accelerate the corrosion; however, the rate of corrosion will decrease with further increase of temperature because of the very low oxygen concentration in the solution. Experimental data confirm this supposition. Figure 172 depicts the rate of iron corrosion as a function of temperature.

When oxygen can evolve from the solution with the increasing temperature (an open system), one obtains a curve with a maximum. The decline of the curve following the maximum is explained by the oxygen deficiency in the solution. When oxygen cannot escape from the solution (a closed system), the corrosion rate continuously increases with temperature. A similar explanation applies to the curve in Figures 173 and 174 depicting the influence of temperature on corrosion of Monel-metal in a solution of sulfuric acid and of copper in 10 percent solution of NaCl, respectively.

Finally, in evaluating the influence of temperature on corrosion, one should also consider the properties of the protective film. If the latter are temperature dependent, the change in the corrosion rate often can be attributed to this dependence.

An experiment with Zn corrosion in distilled water is very instructive (Figure 175). The diagram shows that with the increase of temperature from 50 C up, the rate of corrosion first increases, reaches a maximum and then drops abruptly almost to zero. In the temperature interval 50-95 C the film formed on the metal has weak protective properties, whereas at temperatures below and above this range the film has high protective properties.

Corrosion by Stray Currents[4]

Stray currents may cause serious damage to the underground parts of metallic structures, pipe-lines and lead sheaths of cables. Figure 176 shows schematically how the stray currents may originate.

If the resistance of the ground is not very great, the direct current returning along the rail may branch off and a part of the current might flow along a pipe located nearby. At some other point, the current might return to the rail, directly or through some other conductor, such as an underground cable. The point of the transition of the current to the pipe will be the cathode, the point where the current leaves the pipe will be the anode. The sections of the pipe or of the cable from which the current returns to the ground and then passes to the other conductor (i.e., the anodic sections), will be subject to an intense corrosion. The section of the rail from which the current passes into the ground will also corrode. The corrosion will be of the anodic type, i.e. it will be equivalent to the destruction occurring during dissolving of metal (anode) due to an external electromotive force (Figure 177).

The destruction in this case will be very extensive because the anodic and the cathodic sections are separated in space, and therefore, the protective films which often are formed by interaction of anodic and cathodic products of corrosion and which slow down the development of the process, can not be formed. The existence of stray currents can be demonstrated by a simple laboratory experiment. Figure 178 depicts a section AB of a copper wire immersed in a solution of NaCl to which a ferroxyl indicator is added for detection of anodic and cathodic sections, and gelatine for prevention of spreading of the coloration at the anodic and cathodic sections. A plate of pure iron is placed in the solution parallel to the wire. If the resistance of the wire is very small, the current flows

only through the wire, and there is no branching off of the current through the solution and into the iron plate. But as the resistance of the circuit is increased by the introduction of a rheostat, a part of the current will flow along the path of the least resistance—through the solution, the plate and back into the solution and the wire. This will become apparent because of the red coloration of the cathodic part of the plate and the blue coloration of the anodic part. The red coloration will appear also at the cathodic zone of the conductor AB at the point of current entrance.

The electromotive forces which determine the magnitude of the corrosion current may be very strong in the presence of stray currents, so that, at the cathodic sections, even free hydrogen may evolve. A current of one amp destroys approximately 10 kg of iron, 11 kg of copper or 37 kg of lead in one year.

Figures 179 and 180 show examples of corrosive destruction of cast iron and zinc pipes. Corrosion of lead sheaths caused by stray currents is particularly dangerous because it is often intercrystalline; in such cases a relatively small loss of metal may result in a serious damage to the cable.

If the current would flow only along metallic conductors without passing into the ground and out again, no corrosion effects would be caused by stray currents. The larger the fraction of the current passing from the metallic conductor (a rail, for instance) into the ground and to another conductor, the greater are the corrosion losses caused by stray currents.

The magnitude of emf between the conductor and the underground pipe depends on many factors (the voltage on the conductor, the position of the pipe with respect to the conductor, and the conductivity of the soil, etc.). Measurements show that often the emf values are between 0.65 and 4.5 V. The current densities also vary greatly. When the current density is 0.1 — 0.3 ma/dm², local attack is barely noticeable; at 0.3 — 0.7 ma/dm² centers of increased corrosion appear; at current densities of the order 0.5 — 2.0 ma/dm² a very extensive destruction of the pipes is observed. Sometimes the magnitude of the stray currents reaches exceptionally high values. For instance, in the New York area, a six inch water pipe carried a current of 70 amps during the peak hours of the transportation system.

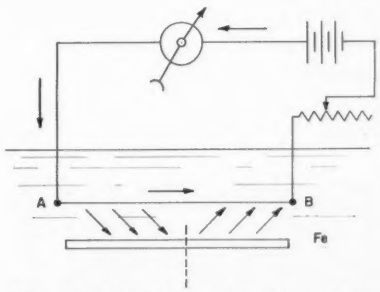

Figure 178—A laboratory experiment for detection of stray currents (Akimov).

The type of soil is also of great importance. The higher the electroconductivity of the soil, the higher will be the fraction of the current branching off into the soil or to other conductors, other conditions being equal. It appears that stray currents are much more harmful in clay soils than in sand soils.

The following measures are possible in combating stray currents:

1. Improving the electroconductivity of the conductor (rail); securing contacts in the junctions of the street car rails, increasing the number of the negative feeder cables for the current returning from the rails. It is also extremely important to use a layer of poorly conducting material, such as gravel under the rails.

2. Covering the pipes and other metallic conductors with insulating material (asphalt, bitumen). It should be mentioned, however, that insulating covers of poor quality in the anodic section can make the situation worse because corrosion, being restricted to a smaller area, may become more intensive.

3. Applying an electric drain. Good results are obtained in some cases by connecting together all underground parts of the structure and connecting them to the negative electric conductor. One would then expect the current to flow only in the metal and not to pass into the ground. However, when this method is not properly applied—when not all underground parts are considered and included into the system of the electric drain—corrosion might be even accelerated in some of the underground parts of the structure. Cathodic protection also has been used successfully.

Stray currents can produce very serious destruction of the iron framework in reinforced concrete, especially when chlorides have been added to the concrete to prevent freezing. This causes the concrete to become electroconducting and the chlorine ions contribute to the destruction of the protective films which are formed on iron under the action of the alkaline concrete. Moreover, the iron chloride which is formed in the corrosion process, reacts with the alkaline concrete forming ferrous hydroxide resulting in a considerable increase of volume. This causes cracking of the concrete, which in turn accelerates the corrosion and the destruction of the whole structure. A number of buildings and bridges in America made of reinforced concrete have disintegrated for this reason.

Stray currents may be caused by things other than electric trains. Poor insulation of the DC wiring in industrial buildings also can produce "internal" stray currents which under unfavorable conditions may cause corrosion of pipes, bathtubs, appliances and other equipment. Stray currents may develop on ships in the docks during welding if one of the terminals is connected to the hull of the ship. Wiring improperly made on a ship (poor insulation, one line system) may also produce stray currents and a destruction of the hull plates and of the rivets in the underwater part of the ship.

Internal Factors

Periodic System and Chemical Stability of Metals[1]

Let us consider the position of metals in the periodic system in connection with their chemical stability. As was already mentioned, the chemical stability of metals is not a simple, definite property; a metal, stable in one set of conditions, may be unstable in another. Nevertheless, it is possible to give a rough evaluation of the chemical stability for those metals that are more familiar to us with respect to their behavior in practice, in relation to their position in the periodic system of the elements (Table 18). Attention is called to the somewhat unusual arrangement of the elements in the table: the A groups are located in the left part of the table, the B groups in the right part, and the transition elements in the middle. The non-metals are separated from the metals with a heavy line. The chemical stability of the least and of the most stable metals is indicated in the table by legends (explained at the bottom of the table).

Group IA is formed by the alkali metals (Li, Na, K, Rb, Cs). These are the least stable metals. They are easily destroyed in water with the evolution of hydrogen.

In group IIA are the alkali earth metals (Be, Mg, Ca, Sr, Ba), which also are not very stable chemically, although their resistance to corrosion is much higher than those in group IA. The oxides of Be and Mg are insoluble in water. The higher corrosion resistance of these metals in humid air and in some water solutions is connected with the formation of protective films.

It is interesting that Sr, the oxide of which dissolves easily, corrodes in water,

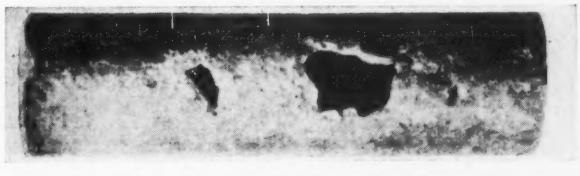

Figure 179—Cast iron pipe damaged by corrosion as a result of stray currents (Maas).

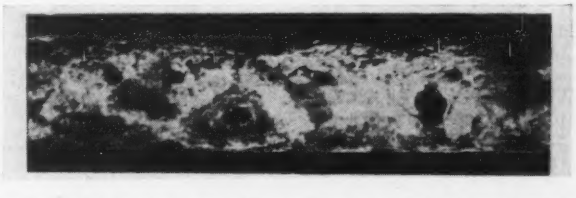

Figure 180—Zinc pipe destroyed by corrosion as a result of stray currents (Mass).

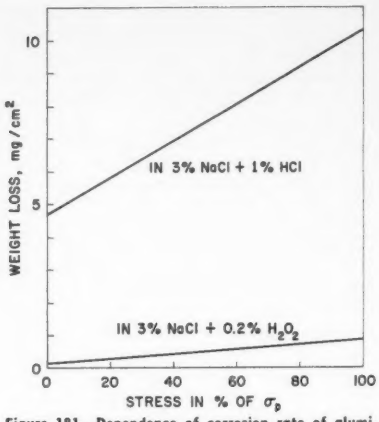

Figure 181—Dependence of corrosion rate of aluminum upon stress (Krenig).

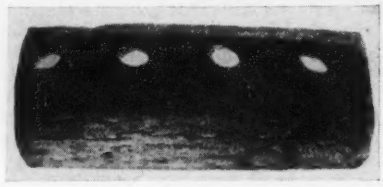

Figure 182—Cracks in the bend of a boiler plate.

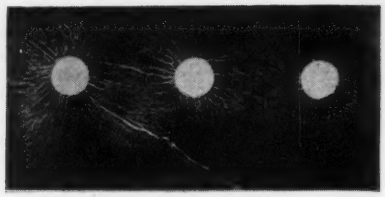

Figure 183—Network of cracks around rivet holes.

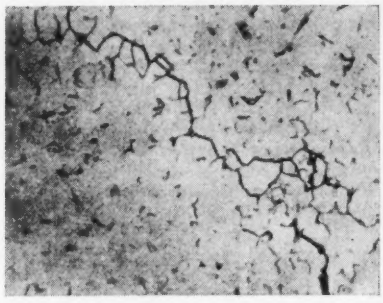

Figure 184—Intercrystalline corrosion of boiler plate (Rapp and Straub).

but is fairly stable in concentrated H_2SO_4 and HNO_3 because of formation of insoluble protective films.

Group IIIA contains only one technically important metal—Al. Its chemical stability depends on the physico-chemical properties of the film Al_2O_3, which is formed by the action of oxygen in air. If the protective film is removed from the aluminum surface by amalgamation or by treating with alkalies, then Al turns out to be a very active material and corrodes rapidly in water with hydrogen evolution.

There are no technically important metals in group IV A. In the Group V A are the metals Nb and Ta, the high chemical stability of which is apparently connected with the presence of stable protective films. The metals Cr and Mo of the group VI A, which are important with respect to corrosion, belong to the chemically stable metals. The corrosion stability of these metals also depends on the ease of their passivation and the ability of forming thin but very stable protective films.

Group VII A contains Mn which is chemically not very stable. The latter corrodes rapidly in air and in many electrolytic solutions. Re, which is in the same group, apparently is much more stable.

The transition group includes a number of technically important metals. In the upper part of the group are Fe, Co, Ni. The chemical stability of these metals is connected with the ease of passivation, as well as with the low rate of reaction of the transfer of metallic ions into solution and the low rate of ion discharge. To the same group belong the chemically very stable metals Pt, Ir, Os, Rh, Pd.

The stability of these metals appears to be their inherent property, although it is known that Pt belongs to the group of metals that are easily passivated.

In group IB are the relatively stable metals Cu, Ag and the chemically very stable Au. It should be mentioned that Cu and Ag have a poor stability with respect to sulfur compounds. The chemical stability of metals of these groups increases from top to bottom (i.e., with an increase in the atomic number of the element).

The next group IIB includes the technically important Zn, Cd, Hg. The chemical stability also increases here with an increase in the atomic number. The first two metals—Zn and Cd—are chemically unstable and corrode easily in diluted acid solutions. Mercury differs greatly from the preceding metals with respect to corrosion stability and resembles copper and silver.

Group IIIB has no technically important metals. Metals of group IVB (Sn, Pb) and of group VB (As, Sb, Bi) are chemically quite stable and corrode slowly in salt solutions and in the non-oxidizing acids. The high chemical stability of Pb in solutions of H_2SO_4 undoubtedly is connected with the formation of a protective film $PbSO_4$.

As previously noted (Chapter III), metals of the groups A (starting with the second group) and of the transition group readily form protective films. The chemical stability of these metals is often connected with the physico-chemical properties of the protective films. Metals of Groups B form protective films to a much smaller extent (although there are also cases here of good films, such as Pb in H_2SO_4), and their chemical stability is apparently connected with the nature of the metal. Finally, it should be mentioned that the chemically most stable metals are located in the central part of the table, in the groups VIII (Os, Ir, Pt) and IB (Au).

Influence of Internal Stresses and Deformations[1]

Structures and machines are subject to various, sometimes very complex, stresses in service. Moreover, modern techniques employ articles and parts which are prepared by deformation of materials without a subsequent annealing, and which display considerable internal stresses. Therefore, the effect of stresses and deformations must also be taken into consideration in the study of corrosion.

Extensive experimental data show that stresses and deformations always increase the rate of corrosion and often worsen its distribution, changing it from a uniform or a local type into intercrystaline corrosion.

Figure 181 depicts the influence of stresses produced by elongation on the corrosion rate of aluminum in different solutions. The stresses are expressed in percent of the stress value corresponding to the proportional limit. The diagram shows that the corrosion rate increases linearly with stress. The curves for brass in 0.5 N HCl, for iron in 0.5 N HCl and

TABLE 18—Periodic System of Elements

	0	IA	IIA	IIIA	IVA	VA	VIA	VIIA	Transition Elements			IB	IIB	IIIB	IVB	VB	VIB	VIIB
1	2	3	4	5											6	7	8	9
H	He	Li	Be	B											C	N	O	F
	10	11	12	13											14	15	16	17
	Ne	Na	Mg	Al											Si	P	S	Cl
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Sc	Br
	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
	Kr	Rb	Sr	Y	Zr	Nb	Mo	Ma	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I
	54	55	56	57	58													
	Xe	Cs	Ba	La	Ce													
				57-71 Rare Earths	72	73	74	75	76	77	78	79	80	81	82	83	84	85
					Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	—
	86	87	88	89	90	91	92											
	Rn	—	Ra	Ac	Th	UX_2	U											

Inert Gases | Metals of Group A | Transition Metals | Metals of Group B | Nonmetals

Very Unstable | Unstable | Very Stable

for Duralumin in 1 N NaCl + 1 percent HCl rise steeply after a certain value of applied stress is reached. In the case of Duralumin, brass and iron, it was observed that the uniform corrosion changes into an intercrystalline type. Stresses produced by torsion and also those produced by other means likewise markedly increase corrosion. If the corrosion rate is controlled by the oxygen supply, the stresses may not affect the general corrosion rate, for understandable reasons.

Deformation of metals acts in the same direction as the state of stress (i.e., it accelerates the corrosion rate and has a tendency to transform it into intercrystalline corrosion). Annealing of the deformed metal and restoring it to the original state may again reduce the corrosion rate, bringing it to the normal values; this might prevent intercrystalline corrosion. Intercrystalline destruction of deformed brasses is of a particular practical importance. This phenomenon is called "season cracking," or "season brittleness."

Deformed brass, under the action of such reagents as $(NH_4)_2SO_4$, NH_4OH and salts of mercury, is subject to a rapid intercrystalline corrosion and develops cracks. It should be mentioned that the intercrystalline destruction does not occur in all media. For instance, deformed brass corrodes uniformly in nitric acid without exhibiting attack of the intercrystalline type. Both the α- and β-brasses develop season cracking.

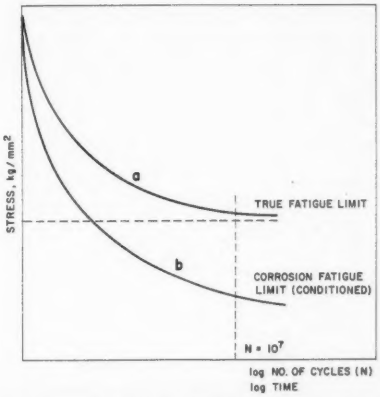

Figure 185—Woehler's diagram for pure fatigue and for corrosion fatigue.

The process is sometimes so intensive that the material splits spontaneously into separate "filaments" or breaks up into small particles. Season cracking damages the condenser tubes of steam power plants, brass boxes, articles made of extruded brass and exposed in air or underground, etc. The main means of combating season cracking is by the removal of stresses by annealing. For 70 percent Cu-30 percent Zn brass annealing must be conducted at 275 C for one hour; for 60 percent Cu-40 percent Zn a 3-hour annealing at 100-125 C is sufficient.

Stresses also contribute greatly to the formation of the so-called caustic embrittlement of iron and steel. "Caustic embrittlement" takes place under the action of alkalies on iron and steel at elevated temperatures and results in a large reduction of the ductility of the material due to the destruction of the grain boundaries. This is of a great practical importance, because caustic embrittlement endangers high pressure steam boilers and chemical apparatus that have contact with basic solution, especially at elevated temperatures and pressures. Water prepared by modern methods for feeding the boilers might be basic to some extent. Moreover, the natural alkalinity of the feed water in some localities must also be considered. Sodium bicarbonate in the feed water is decomposed in the boiler at elevated temperatures and pressures, with formation of sodium hydroxide.

Under the working conditions of a boiler, the alkalies might act upon iron by forming sodium ferrate Na_2FeO_2 and hydrogen. The corrosion process develops mainly on the grain boundaries of the metal under stress. Once started, the process might be accelerated because the internal stresses separate the grains along the weakened boundaries, a crack is formed, and water can penetrate still further into the metal, thus further spreading the intercrystalline corrosion.

It is possible that absorption of the evolving hydrogen by the metal is to some extent instrumental in the deterioration of metal.

Figure 182 shows a piece of a boiler plate with cracks in the bend. Cracks are also formed around the rivets and along the rivets themselves (Figure 183). The intergranular character of the cracks can be seen in Figure 184.

Caustic embrittlement also appears in the iron sheets and in the rivets of barrels containing alkalies, in the cauldrons and other apparatus of the chemical industry that are in contact with alkaline solutions, especially at higher concentrations and at elevated temperatures and pressures.

Choosing suitable materials and proper treatment of the water fed into the high pressure boilers, are the means for prevention of caustic embrittlement.

Caustic embrittlement occurs particularly easy in steel with a high nitrogen content. Steels containing nickel are resistant to caustic embrittlement. Steels containing 3 to 5 percent nickel have found practical application.

Sodium sulfate is added to the boiler water for reduction of caustic embrittlement, because when the concentration of the alkali in the joints and seams becomes dangerous, sulfate precipitates and protects the metal from the action of alkali. The substitution of sodium carbonate used as boiler water softener, by sodium phosphate also can bring helpful results.

The mechanism of the influence of internal stresses and deformations on corrosion is not yet definitely established. Of great importance is, undoubtedly, the potential change in the intercrystalline boundaries which is connected with the general lowering of the potential by elastic or plastic stresses of metals (Chapter 3).

Corrosion Fatigue[1]

Machine parts are often subject to the simultaneous action of a corrosive medium and alternating stresses. The alternating stresses by themselves, as well known, cause metal fatigue, and when the fatigue limit (endurance limit) of the material is reached, after several cycles a fatigue crack develops, and the part breaks. The more the alternating stresses exceed the fatigue limit, the shorter the life of the part. It should be mentioned also, that all factors contributing to the concentration of stresses (cuts, sharp changes of the thickness of the part, holes, rough surface finishing) greatly reduce the fatigue limit of the part. The results of testing a material for fatigue can be represented by means of the so-called Woehler diagram (Figure 185).

The abscissa axis represents the logarithm of the number of cycles of the alternating stress load needed for de-

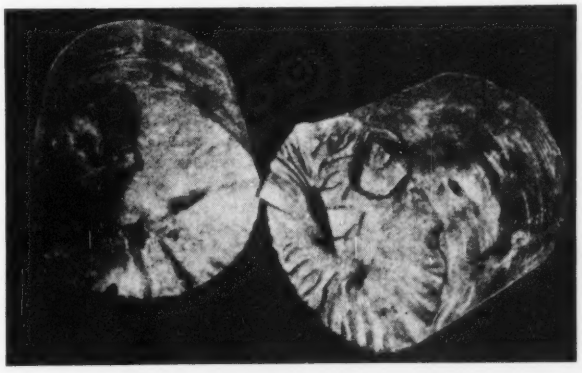

Figure 186—Parts of a steamship shaft (Hoff).

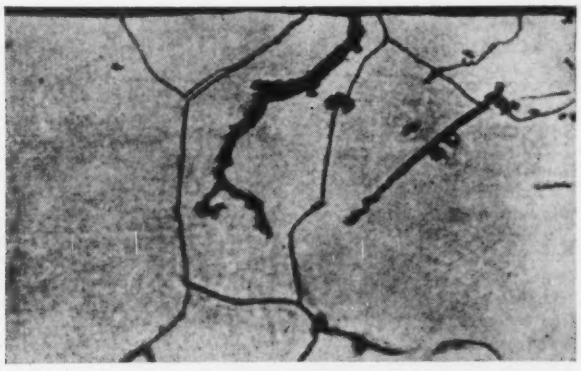

Figure 187—Transcrystalline cracks in soft iron developed by corrosion fatigue in sea water (Hoff). 750 X.

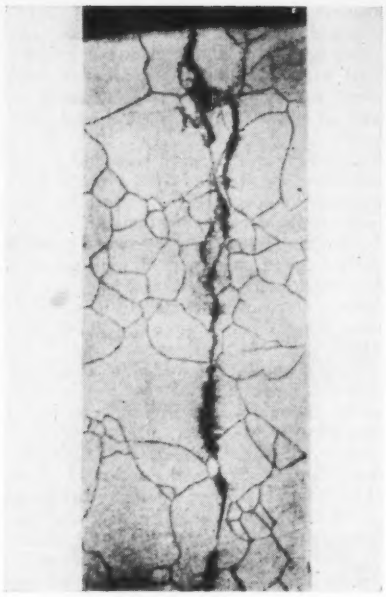

Figure 188—Transcrystalline crack in a steel sample (18 percent Cr, 8 percent Ni, 1 percent W) that was destroyed by corrosion fatigue (Hoff). Solution was $(NH_4)_2SO_4$. 100 X.

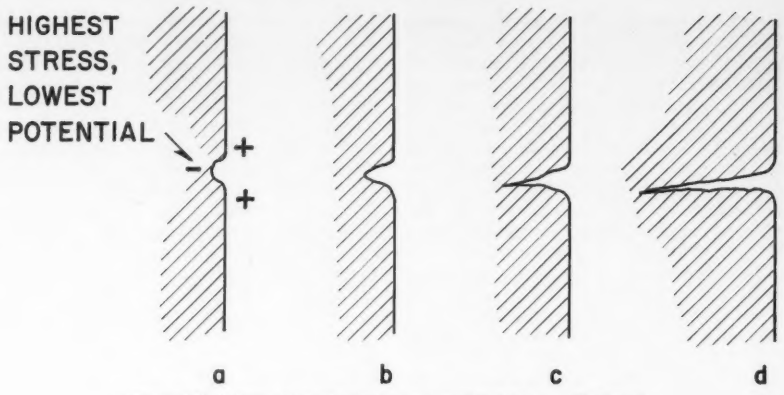

Figure 189—Scheme of development of a corrosion fatigue crack (Evans).

struction of the sample, the ordinate is the corresponding stress in kilograms per 1 mm.^{2} When the number of cycles per minute is known, the time scale also can be plotted on the abscissa axis. It follows from the diagram that below a certain value of the stress (fatigue limit) the material is not destroyed even at a very high number of cycles, because the curve *a* is parallel to the abscissa axis. This type of fatigue diagram is characteristic of most metallic materials. Simultaneous action of alternating stresses and corrosion greatly lowers the Woehler's curve. It turns out that the material does not then have a true fatigue limit, as the curve continues to decline (curve *b*). This is understandable, because even in the absence of alternating stresses, the sample, after a sufficiently long time, would be destroyed by "pure" corrosion. Thus, the limit of corrosion fatigue (i.e., the fatigue limit under the simultaneous action of alternating stress and corrosion), can be determined for a set number of cycles.

It should be emphasized that the effect of corrosion fatigue is much greater than the sum of the separate effects of corrosion and fatigue. In Table 19 data are given for the values of the limits of corrosion fatigue compared with the usual fatigue limits for various materials. In the same table the values of tensile strength are given characteristic of the strength of material.

Corrision fatigue must be taken into account in many technical fields. Figure 186 depicts parts of a shaft of a steamship propeller destroyed by corrosion fatigue. Corrosion fatigue greatly affects coupling rods of pumps, discs and vanes of turbines, steel cables operating in sea water, trolley and railway car springs, parts of escavators and mining machines, cooled rollers of the rolling mills, steam superheaters and so forth.

Alternating stresses do not cause an increase of general corrosion. The accelerated destruction of parts results from a premature appearance of corrosion fatigue cracks. These cracks differ somewhat from the usual fatigue cracks. In cases of corrosion fatigue, there is often a network of microscopic cracks which turn into one large crack, whereas in cases of the usual fatigue, as a rule, only one crack appears.

The cracks of corrosion fatigue can be transcrystalline as well as intercrystalline. Figures 187 and 188 present typical cracks caused by corrosion fatigue.

Destruction by corrosion fatigue can proceed in the following manner: first, small local sites of attack appear on the metal surface as a result of a corrosion process, for instance, in a form of a shallow pitting (Figure 189). Such a pitting will act as a notch with respect to concentration of stresses, with the maximum stress values located at the bottom of the pits. For this reason, the bottom of the pit will have a more negative potential than the walls of the pits and the outer surface of the metal and consequently will be the anodic area. The lowering of the potential at the bottom of the pits may be connected with the destruction of the protective film beginning to form, under the action of alternating stresses, as well as with the pure effect of stresses (Chapter 4, 7). Thus, the pits will have the tendency to become deeper, as indicated in the consecutive stages of the development of the crack (b, c, d) in Figure 189. Deepening of the crack makes the latter increasingly narrower and sharper. The fatigue factors will have an increasingly larger influence on the consecutive development of the crack and on the final destruction of the material. Figure 190 depicts the cross-section of a piston rod, which was water cooled from inside, of a naval Diesel engine. Small cracks of corrosion fatigue can be seen on the cooled surface.

The fracture of this part is depicted in Figure 191. A crack caused by corrosion fatigue in a spindle of a water pump is shown in Figure 192. The picture of the destruction of the tubes of a superheater caused by corrosion fatigue is given in Figure 193.

Many factors, which reduce corrosion in general, also reduce the effect of corrosion fatigue. If oxygen is removed from the solution or a sufficient amount of chromates is added, the limit for corrosion fatigue is raised; the limit of corrosion fatigue for the stainless steels is higher than for the carbon steels or low alloy steels. Exceptionally high limits for corrosion fatigue were found in the nitrided articles (Table 19). The nitrided articles are usually made from chromium-aluminum steels. It should be mentioned, however, that in many cases, besides the chromium-aluminum steels, one can successfully use the more ductile chromium-molybdenum-vanadium steels, on which one can also obtain an excellent nitrided layer.

Influence of Surface Condition

Fine finish of a surface, as a rule, increases the corrosion stability. In Chapter 1 it was mentioned that the protective

TABLE 19—Corrosion Fatigue of Metals (Evans)

Metal	Tensile Strength in kg/mm^2	Fatigue Limit at 5.10^7 Cycles kg/mm^2	Limit of Corrosion Fatigue at 5.10 Cycles, kg/mm^2	
			Fresh Water	Sea Water[2]
Carbon steel (0.25% C)	39	16.5	12	..
Copper steel (0.15 C, 1% Cu)	42	22	14	6.0
Nickel steel (3.7% Ni, 0.25% C)	63	34	15.5	11.5
Chromium-nickel steel (1.5% Ni, 0.73% Cr, 0.28% C)	97	47	11.5	9.5
Chromium stainless steel (13% Cr, 0.11% C)	62	38	26	21
Chromium-nickel stainless (18% Cr, 8% Ni, 0.15%C)	60	28	17.5	..
Nickel	53	24	16	..
Copper	21	7	7	..
Aluminum bronze (7.5% Al)	63	23	18.5	16
Duralumin	56	13	7.5	6
Steel for nitriding				
1.6% Cr, 0.9% Al, 0.3% Mo, 0.25% C – not nitrided	..	51	8	..
1.6% Cr, 0.9% Al, 0.3% Mo, 0.25% C – nitrided	..	58	39	..

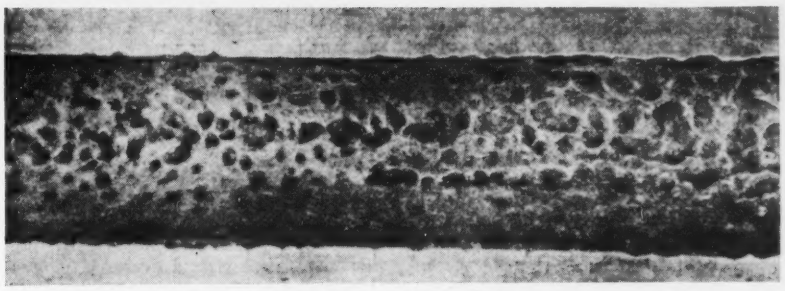

Figure 190—Piston rod of a naval Diesel engine destroyed by corrosion fatigue (Hoff).

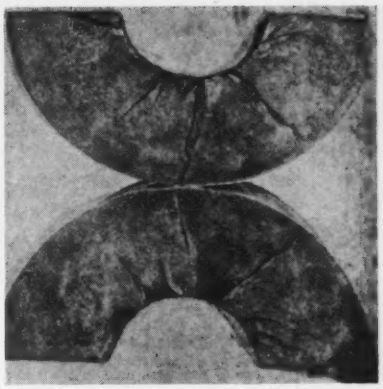

Figure 191—Fracture of the piston rod (Hoff).

Figure 192—Cracks caused by corrosion fatigue of a water pump spindle (Hoff).

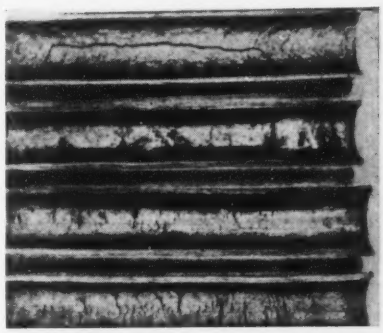

Figure 193—Cracks in the tubes of a steam superheater caused by corrosion fatigue.

film is better on a fine finished surface than on a rough surface.

When the reagent is highly corrosive, and the rate of corrosion is great, then, naturally, the difference in the corrosion rates for surfaces of different finishes is not great. This is because after a short time the surface conditions become equal as a result of corrosive destruction. Fine surface finish (fine grinding, polishing) is especially important in atmospheric corrosion. The corrosion centers are formed considerably later on a polished surface than on a roughly finished surface. The fine finish of the surface also raises the corrosion fatigue limit.

Freshly finished surfaces, for instance, immediately after sandblasting, are often unstable, and centers of corrosion attack develop easily. Only after some exposure to air and formation of the natural protective film, the corrosion stability becomes normal. Therefore, the freshly finished surfaces of articles must be carefully protected during manufacturing as well as during storing. The sweat from hands also can cause intensive corrosion of freshly finished surfaces. It is therefore necessary in some operations of precision machining (manufacturing of apparatus, of ball bearings, of measuring instruments) to work with rubber or suede gloves. Washing the hands often also gives good results. For protection of freshly polished parts one has to apply careful rinsing, passivation in phosphate reagents and temporary lubrication. The proper composition of inhibitors in the emulsions used for facilitating the machining of the parts is also very important.

Structure of Metals and Chemical Stability[2,3,4]

Pure Metals. Influence of Grain Size. Investigations of corrosion of brasses in dilute acids, and studies of corrosion of marine condenser tubes have shown that the grain size affects the corrosion rate to only a small extent. The corrosion rate of iron and aluminum, according to existing data, is also little affected by the grain size. Only when the impurities precipitate on the grain boundaries, and the conditions are such that the corrosion becomes intercrystalline, one can expect a noticeable increase of corrosion along the grain boundaries as the grain size increases. The total extent of the boundaries in a large-grain metal is smaller than in a small-grain one, and consequently the intensity of corrosion per unit length on the boundary is larger.

Heterophase Alloys. We shall divide all alloys into two groups—heterophase and monophase. The first group includes alloys consisting of more than one structural component; the alloys of the second group have only one structural component. Only solid solutions shall be considered in the second group, since alloys forming pure intermetallic compounds have no practical applications at all.

Among the heterophase alloys is the practically important eutectic (and eutectoid) group. Alloys such as silumin (a silicon-aluminum alloy) and carbon steel with 0.9 percent carbon, belong to this group.

In analyzing the corrosion behavior of heterophase alloys, we have to take into account the following conditions:

1. The values of the initial electrode potentials of the structural component and the division of the surface of the alloy into anodic and cathodic regions, as a result of these potentials. The extreme cases are: (1) $f_A \geqslant f_K$ and (2) $f_K \geqslant f_A$, where f_A is the area of anodic regions and f_K the area of cathodic region.

If the area of the anodic component is small in comparison with the cathodic area, and the anodic component is uniformly distributed in the cathodic component then from the very commencement of corrosion, the anodic areas might be subject to an extremely intense and rapid attack. In such a case after a short time there will be no anodic regions on the surface of the alloy, and the corrosion will proceed because of the action of corrosion cells of some other kind. An example of this kind is the behavior of the component Mg_2Si in corrosion in sea water of aluminum alloys containing among other elements also small (up to 1 percent) amounts of magnesium and silicon. Small sections of this constituent are soon destroyed leaving in their place dark pits, visible under a microscope, which are partly filled with corrosion products.

Cathodic inclusion in an anodic component, when they are not strongly polarized, will cause, of course, an intense corrosion of the anodic base; this subject was already discussed in Chapters 3 and 4.

2. Distribution of anodic and cathodic regions in connection with the properties of the structure of the alloy. The extreme cases are:

(1) The component having a smaller area is uniformly distributed in the basic component as inclusions.
(2) The structural component having a smaller area is concentrated along the grain boundaries.

When the components are uniformly distributed, the alloy is less likely to be subject to intercrystalline corrosion than when one of the components is concentrated along the grain boundaries. However, intercrystalline corrosion depends on more than just the type of distribution of the components.

In the previous sections we have already dealt with the influence of stresses in brass (homophase alloy) and with the resulting intercrystalline corrosion. An anodic component, present in the alloy even in relatively small amounts, may be distributed in such a manner that it forms a continuous path. In this case the alloy can be destroyed very rapidly because corrosion quickly penetrates the metal, and particles of the cathodic component

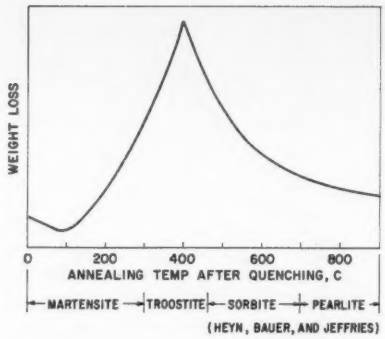

Figure 194—Corrosion of quenched and annealed eutectoid steel (about 0.9 percent C) in 1 percent sulfuric acid for 72 hours (Heyn, Bauer and Jeffries).

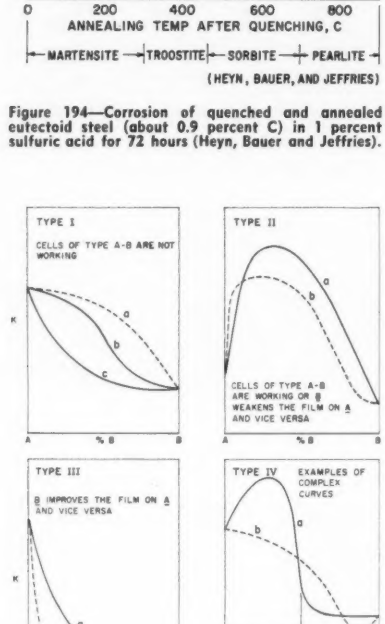
TYPE I
CELLS OF TYPE A-B ARE NOT WORKING
TYPE II
CELLS OF TYPE A-B ARE WORKING OR B WEAKENS THE FILM ON A AND VICE VERSA
TYPE III
B IMPROVES THE FILM ON A AND VICE VERSA
TYPE IV
EXAMPLES OF COMPLEX CURVES
ACTION OF CELL A-B PREVAILS
IMPROVEMENT OF FILM PREVAILS
% B

Figure 195—Dependence of corrosion on the composition for binary heterophase alloys (Akimov).

fall out, exposing new regions of the anodic components, etc.

When the destruction mainly affects one phase, the corrosion is called selective. This type of corrosion often affects the two-phase brasses. Only the β-phase which is located on the grain boundaries of the α-phase is destroyed.

3. The size of the structural components. Diminishing the size of the structural components in eutectics often results in a noticeable increase of corrosion stability. For instance, the eutectic Zn-Cd with larger structural components is rapidly destroyed in dilute hydrochloric acid. However, if a fine structure of this eutectic is obtained by quenching, then the hydrochloric acid acts much slower. The behavior of the alloy Cu-Ag in ammonium hydroxide is similar.

For some alloys, there is a critical value of the size of the structural components corresponding to the maximum corrosion rate. When the sizes of the microcomponents are larger or smaller (in comparison with the critical value), the rate of corrosion is lower.

Figure 194 represents the dependence of the rate of corrosion of quenched eutectoid steel (0.9 percent C) in dilute H_2SO_4 on the annealing temperature.

We can assume that in annealing of quenched steel there is a precipitation and a gradual growing of Fe_3C particles, which in this case represent cathodic components. The maximum corrosion occurs when annealing is at 400 C. When the annealing temperature is further increased, the Fe_3C particles coagulate and, consequently, the number of microelements decreases. The descending left part of the curve corresponds to the commencement of martensite decomposition, when the Fe_3C particles are still very small. In this case the action of the microcells is also weaker. It is possible that the lowering of the curve is also connected with the removal of the internal stresses.

4. Polarization property of structural components. Anodic polarization is particularly important, for understandable reasons, when the anodic component has a much smaller area than the cathodic component. If the corrosion proceeds with hydrogen evolution, the important characteristic of the cathodic component is its hydrogen overvoltage, whereby the corrosion conditions such as pH, the presence of extraneous ions in the solutions, etc., must, of course, be taken into consideration. When the overvoltage on the cathodic structural component is higher than on admixtures that may be present in the metal, then, of course, the cathodic regions will accelerate the corrosion of the anodic component only a small amount (i.e., they will be weak cathodes). Such cases are quite possible when the corrosion process depends on corrosion cells caused not by the nonuniformity of the alloy, but by the presence of some admixtures and even by the macroheterogeneity of the boundary between the metal and solution. In processes with oxidizing depolarization the structural nonuniformity may not influence the corrosion rate, for reasons discussed above (Chapter 4).

5. Secondary precipitation of the more noble component. This question was already discussed in Chapter 3. As a rule, the secondary precipitation increases the corrosion rate.

6. Possibility of formation of insoluble films made of the corrosion products in the immediate vicinity of the metal. It is more probable to obtain a uniform protective film when the size of the structural components is small, than when it is relatively large. Cases are possible when the formation of the second phase will impair the film and lower the chemical stability of the alloy.

Thus, it is evident that the problem of corrosion of even the simplest binary heterophase alloys is very complex, and it is not surprising therefore, that there are so many contradictions and unsolved problems in this part of the corrosion theory. It must be mentioned also, that there are not many rigorously confirmed experimental data. The difficulty of the experimental study of corrosion of alloys is caused by the necessity of using extremely pure reagents and materials for making the alloys, which are often not available in many laboratories, especially, when considerable amounts of materials are required for experiments. Taking into account the most important factors, i.e., the electrochemical properties of the anodic and cathodic components and the influence of the composition of the alloy on the film (with respect to improving or weakening its protective properties), the dependence of the corrosion stability upon the composition of binary heterophase alloys can be schematically presented in three typical diagrams (Figure 195), where *a, b, c* are separate examples for the diagram of each kind.

The results of corrosion tests with heterophase alloys often depend on the methods of measurements. If the corrosion is selective, and if the alloying component that is being destroyed penetrates the metal as a coherent network, the results obtained may be similar to those of intergranular corrosion, that is, while the weight loss may be relatively small (or the weight may even increase), the mechanical properties of the alloy after corrosion may be greatly affected. Of course, this is true in the case of agents which are not very strongly corrosive (such as fresh water and sea water), when the insoluble corrosion products of the less electropositive component remain in the metal and the more noble grains do not precipitate.

In the theory of corrosion there is a widely shared opinion that the homophase alloys are definitely superior, with respect to corrosion stability, to the heterophase alloys.

In most cases this is correct. However, there are many cases when the heterophase alloy is also chemical stable. For instance, the corrosion resistant silumin is essentially an aluminum-silicon eutectic; the eutectic Pb-Bi is more stable in a H_2SO_4 solution than Bi; the very corrosion-stable iron-silicon alloys have the structure: solid solution (FeSi) + eutectic (FeSi-Si).

Solid Solutions. In his study of the chemical stability of solid solutions, Gustav Tammann has experimentally established a remarkable rule, known as Tammann's law, or "the $\frac{n}{8}$law."

Let us consider the system Cu-Au which is known to form a continuous series of solid solutions. We shall determine the chemical stability of alloys of this system in a reagent that strongly reacts with one of the components and does not react at all with another. Strong nitric acid is such a reagent; it destroys copper rapidly and practically does not react with gold.

The results of determinations of the chemical stability of this system in HNO_3 are given in Figure 196. The composition of the alloys, in fractions of a mole, is plotted on the abscissa. Zero on the abscissa axis corresponds to 1 mole Cu, the unit is 1 mole Au. The numerical values on the abscissa indicate the fraction of 1 mole of Au in the alloy. On the ordinate axis, the values of the chemical stability of gold are plotted, indicating that it is practically insoluble under these conditions.

It follows from the diagram that when the gold content exceeds 0.5 mole, the alloys are perfectly stable and do not differ in this respect from pure gold. When the gold content is below 0.49 mole, the alloys are very similar to copper with respect to chemical stability. Thus, in a very narrow range 0.49 — 0.5 mole, there is a very rapid change of chemical stability of alloys—from a complete instability to a perfect stability.

A detailed study of the behavior of Cu-Au alloys in other solutions has demonstrated that in some reagents there is also a sudden change to a perfect chemical stability of the alloy as soon as the copper content is decreased below a certain limit. In Table 20 the results of a study of the system Cu-Au are given. The data show that a rapid change of chemical stability also occurs in other than HNO_3 reagents, only it happens at different alloy compositions—at 0.25 and even at 0.12 mole Au.

It is remarkable that these values correspond to 1/8, 2/8, and 4/8 mole. Studies of other systems forming solid solutions show that the stability limit occurs mostly at 2/8 and 4/8 mole, but the values of 6/8 and 7/8 mole are also possible. Thus, the stability limits are observed at values n/8 mole of the nobler component. This explains the name "the n/8 law" for the regularity found by Tammann.

In Table 21 are given the values of the stability limits for different systems of solid solutions. The stability limits can be observed only when one of the components of the solid solution has, under given conditions, a very high, and the other—a low stability. Moreover, there should be no appreciable diffusion in the alloy. Therefore, in the liquid alloys, such as amalgams, the stability limits are not observed.

It can be seen from the above data that the location of the stability limit depends not only on the system itself, but also on the reagent.

The existence of the limits of chemical stability must be considered proven by extensive experimentation. However, in a number of cases, the stability limit is not observed at all (Table 20). In other cases, the stability limit might be considerably displaced with respect to the theoretical value n/8. Thus, for instance, the system Cu-Pt in solution of $PdCl_2$, HNO_3, $HgNO_3$ has a stability limit at 0.27-0.32 mole; the stability limit in the system Ag-Pt in solutions of HNO_3, $HgNO_3$ and some others is at 0.35 mole and higher. Similar deviations appear also in other systems. Sometimes the stability limit is not very sharp; there is an interval with a gradual change of chemical stability of the alloy.

The stability limits are observed both in electrolytes and in reagents that are not electrolytes and whose action is purely chemical (for instance, the action of an ether solution on the alloys of the system Mg-Cd or the action of a solution of S in CS_2 on the alloys Cu-Au).

The stability limits were found also in the dissolution of some salt alloys which form solid solutions, for instance, in the dissolution of the sold solutions NaCl and AgCl in water (the stability limit is at 0.5 mole).

The protective action of the nobler component in a solid solution is undoubtedly connected with the formation of a "barrier" of atoms of the chemically stable compound that is impermeable to the reagent. Concerning the mechanism of the "barrier" formation, several suppositions were made. Firstly, an ordered distribution of the atoms of solid solutions in the space lattice can be imagined, such that when concentrations of the nobler component of 1/8, 2/8 etc., mole are reached, the lattice of the alloy forms planes particularly rich in atoms of the insoluble component. Under the action of the reagent on the metal several atomic layers of the alloy are destroyed, until crystalline planes are reached consisting entirely of atoms of the noble component, or, at least, very rich in this component. As soon as these planes appear on the surface, the dissolution of the alloy is stopped.

Because of the difficulties associated with the assumption of ordered distribution of atoms of two components in solid solutions, other hypotheses were also suggested.

For instance, the possibility was considered of the destruction of the alloy due to the penetration of the reagent along the "chain" formed by the soluble atoms. Attempts were made to calculate the probability of formation of such chains as a function of the content of the nobler component.

Next, a change of the structure of the surface layer of the alloy was considered that may occur under the action of the solution. X-ray diffraction studies of the alloy Cu-Au containing 0.5 mole Au, treated in a HNO_3 solution, have demonstrated that the surface layer (of approximately 5 micron thickness) is a space lattice of pure gold. The surface layer of alloys containinng less gold, for which the stability limit is at 2/8 mole

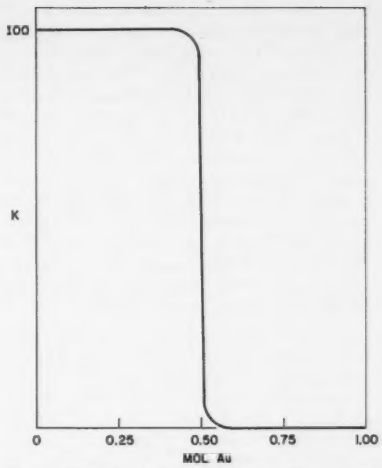

Figure 196—Chemical stability of solid solutions Cu-Au in HNO_3, specific gravity 1.3 at 90 C (Tammann and Brauns).

Au, after treatment with a suitable reagent (for instance, alcohol solution of picric acid), is a solid solution considerably enriched in gold in comparison with the initial alloy.

The increase of concentration of the nobler component in the surface layer may be caused by the transfer of the less noble atoms into solution, as well as by the secondary exchange deposition of atoms of the nobler component that went into the solution during the destruction of the lattice. It must be pointed out that while there is no doubt concerning the existence of the stability limits—this is an empirically proven fact—the numerous attempts to explain the stability limits and their dependence on the acting reagent, should be considered only as very imperfect and often one-sided hypotheses. It is apparent that the problem is so complex and so little understood that further accumulation of rigorously established factual material is necessary, before a sufficiently conclusive theory of the stability limits of solid solution will emerge.

In the field of corrosion of solid solutions there is another similar kind of corrosion attack which can be called "extractive" corrosion. Very little is known so far about this kind of corrosion; however, there is a practically important example of this type of corrosion—the so-called dezincification of brasses.

Brasses (i.e., solid solutions of copper

TABLE 20—Stability Limits of Solid Solutions Cu-Au (Tammann)

Reagent	Limits of Stability Mole Au	Limits of Stability n/8 Mole
HNO_3 spec. gr. 1.3	0.49—0.50	4/8
$PdCl_2$	0.245—0.255	2/8
$(NH_4)_2S$	0.245—0.255	2/8
Picric acid	0.22	2/8
$HgCl_2$	0.24	2/8
Silver salts	0.08—0.15	1/8
HgCl	None	...
$HgNO_3$	None	...
$Hg(NO_3)_2$	None	...

TABLE 21—Stability Limits in Solid Solutions (Tammann)

System	Stability Limits in n/8 Mole of Metal			
Cu—Au	1/8 Au	2/8 Au	4/8 Au	.....
Ag—Au	.....	2/8 Au	4/8 Au	.....
Zn—Au	.....	.....	4/8 Au	.....
Pd—Au	.....	.....	4/8 Au	.....
Mn—Ag	.....	.....	.....	6/8 Ag
Zn—Ag	.....	2/8 Ag	.....	.....
Ag—Pd	.....	.....	4/8 Pd	.....
Cu—Pd	.....	.....	4/8 Pd	.....
Ni—Pt	.....	2/8 Pt	.....	.....
Mg—Cd	.....	2/8 Cd	.....	.....
Cu—Ni	.....	2/8 Ni	4/8 Ni	.....
Fe—Si	.....	2/8 Si	.....	.....

and zinc) often corrode in such a way that in the process of corrosion only zinc is removed from the brass, and the alloy is enriched in copper. For instance, if the ε-brass with high Zn content is acted upon with HCl solution of high concentration, then both zinc and copper pass into the solution simultaneously, but copper is redeposited on the alloy as copper sponge. When ε-brass is acted upon by a weak solution of HCl or a solution of acetic acid, only zinc is removed from the alloy, and the ε-brass is transformed first into a γ-brass, then into β-brass, and finally only pure copper remains.

Thus, it appears that the dezincification of brass can proceed in two different ways. In one case, both the zinc and the copper ions pass simultaneously into the electrolyte during the destruction of the lattice of the solid solution. Subsequently, copper is redeposited as a layer of low density, as a result of secondary precipitation. In the other case, only the zinc ions migrate from the metal into the solution. It should be assumed that in a mechanism of this kind, the anodic reactions proceed mostly with the ions of zinc, whereas the cathodic reactions, predominantly with the ions of copper. The surface of the metal can be considered in this case as a system of microcells of submicroscopic dimensions.

Experiments have demonstrated that the dezincification of brass depends greatly on the external conditions. For instance, a sheet sample of brass of 1 mm thickness, in a solution 1 N HCl was completely dezincified in 5 weeks, when the liquid was stationary; no traces of copper could be found in the solution. A similar sample in the same solution, when rotated, corroded slowly as a whole, without dezincification. Thus, by facilitating the removal of the copper ions from the surface by rotation of the sample, the secondary deposition of copper is hampered. In anodic dissolution of brass it is also possible to obtain either the uniform (with respect to zinc and copper) corrosion, or dezincification, depending on the conditions.

Dezincification is observed also in numerous practical cases of corrosion of brass in sea water and in fresh water. In general, brasses with higher zinc contents are more subject to dezincification. Brasses with less than 20 percent Zn do not display dezincification. When water acts upon brass, dezincification is often only local and is discontinuous. Dezincification considerably reduces the quality of the material by lowering the yield strength and by reducing the elongation. Cracks are also observed, especially when the parts are under stress.

The presence of a small amount of arsenic in the brass (0.02 percent) prevents dezincification to a considerable extent. Therefore, in practice arsenic is added, for instance, in manufacturing condenser tubes. Additions of some other elements—Sn, Ni, Al, W, Pb—also reduce dezincification, although to a smaller extent than As. Manganese and iron apparently accelerate dezincification. The reason for this influence of the above mentioned metals is not clear yet.

The study of chemical stability of solid solutions also must take into account the increase of the binding forces because of the energy of formation. This was already mentioned in Chapter 3.

Bibliography

Ernst Mislowitzer. Die Bestimmung der Wasserstoffionenkonzentration von Flussigkeiten. Berlin; Julius Springer, 1928.

H. T. S. Britton. Hydrogen Ions, Their Determination and Importance in Pure and Industrial Chemistry. 3rd ed. London, Chapman and Hall, 1942. 2v.

Ulick Richardson Evans. Metallic Corrosion, Passivity and Protection. London, E. Arnold & Co., 1948.

Frank N. Speller. Corrosion, Causes and Prevention. New York, McGraw-Hill. 1st ed. 1926. 2nd ed. 1935. 3rd ed. 1951.

Evans. *loc. cit.*, Chapter I.

Evans. *loc. cit.*, Chapters IX, X, XI, XII.

Speller. *Loc. cit.*, Chapter III and IV.

V. V. Scorcheletti and A. I. Shultin. The Chemical Destruction of Metals. (In Russian). Leningrad, Metal Publishing House, 1934. Metallurgical Abstracts, Series 2, V. 2, 1935.

G. Tammann. Die Chemischen and Galvanischen Eigenschaften von Mischkristallen und Ihre Atomvertheilung. Leipzig; L. Voss, 1922. Lehrbuch der Metallkunde. Chemie und Physik der Metalle und Ihrer Legierungen. 4th ed. Leipzig; L. Voss, 1932.

Any discussion of this article not published above will appear in the December, 1959 issue

Action of the XO_4^{N-} Inhibitors

By G. H. CARTLEDGE

Abstract

Experimental studies on the effect of ions and molecules of the type XO_4^{n-} upon corrosion of iron and steel are summarized. Measurements of electrode potentials in inhibited solutions and the effect of foreign electrolytes upon these potentials have shown the competitive and reversible nature of the surface state associated with inhibition. Studies with the pertechnetate ion as inhibitor have demonstrated absence of detectable continuing chemical action in the system over a period of more than five years. Passivation by OsO_4 is so complete that an iron electrode indicates the thermodynamic potential of the Os^{IV}-Os^{VIII} couple. The Flade potential may be observed on iron electrodes in aerated, inhibited solutions without use of such vigorous passivating agents as HNO_3 or anodic polarization. Results are discussed by considering the ways in which presence of an adsorbed inhibitor may affect the kinetics of electrode processes at a metal-solution interface. Specific differences among the XO_4^{n-} particles with respect to inhibition may arise from the nature of the electrostatic field exerted by such particles over short distances.

Introduction

WHEN PROPERTIES of inhibitors and the mechanism of their action are considered, the importance of electrochemical kinetics should be emphasized. When wrapped in something resembling tar paper, a pipe line may be protected to transmit oil or gas for a reasonable time, but the situation has not been changed thermodynamically. Only a diffusion barrier has been interposed to slow the corrosion process. If an inhibitor is added to the fluid in the pipe, only the kinetics of the corrosion process is changed though the inhibitor, depending upon its type, may or may not act like tar paper. One of the cheapest and most effective passivators available is ordinary air, but its action is generally destructive rather than protective unless something is done to give its kinetics a chance to dominate the situation. Hence much as possible should be learned about the factors involved in the kinetics of electrode processes at the interphase between a metal and its corrosive environment.

The theory of reaction rates developed by Eyring[1] has been applied by a number of authors[2] to the kinetics of electrode processes, though most of the work on kinetics has referred specifically to the discharge of hydrogen on metals. The theory assumes that the electrode reaction proceeds through formation and decomposition of an intermediate complex, the formation of which requires an activation energy. The basic equation expresses the current flowing through an electrode as the difference between an anodic current ($M \rightarrow M^{n+} + ne^-$) and a cathodic current. If the electrode reaction rate is controlled by the formation and decomposition of the activated complex (activation control), each of these partial currents can be evaluated in terms of certain constants (which are combined into K), the activity product of the appropriate reactants, a^p, the activity coefficient $\gamma^{\ddagger}$ of the activated complex and an exponential term containing the free energy of formation of the activated complex. This expression for the current with a single anodic and a single cathodic process is shown in Equation (1):

$$i = i_a - i_c = \left[\left(\frac{K}{\gamma^{\ddagger}}\lambda a^p \exp - \frac{A}{RT}\exp\frac{\alpha\lambda F}{RT}\Delta\phi\right)_a - \left(\frac{K}{\gamma^{\ddagger}}\lambda a^p \exp - \frac{A}{RT}\exp - \frac{(1-\alpha)\lambda F}{RT}\Delta\phi\right)_c\right] \quad (1)$$

The exponential is made up of two factors: A is the chemical part of the free-energy of forming the activated complex from its reactants; the remainder is the electrical part, containing $\Delta\phi$, the potential difference, which increases or decreases the over-all free energy of formation of the activated complex from the two sides of the reaction. The quantity α denotes the fraction of the potential difference across the interphase which aids the anodic process, and λ gives the number of charges transferred in each reaction sequence. The other symbols refer to constants: F, the Faraday; R, the gas constant; and T, the absolute temperature.

For systems of interest in corrosion this treatment requires amplification; Posey,[3] in the author's laboratory, has modified the equation in two ways. First, m anodic processes and n cathodic processes can be considered occurring simultaneously at the same site. This makes it necessary to take a summation of m — n terms like the two shown in Equation (1), and placed in parenthesis in Equation (2). Second, the chemical activation energy, A_i, for a particular process must be recognized as varying from place to place over a practical electrode, as from one crystal face to another or to a grain boundary. This makes it necessary, in principle, to express A_i as a function of position and to integrate the exponential terms, exp $(-A_i/RT)$, over the area of the electrode, S. These considerations change Equation (1) into Equation (2):

$$i = \int_S \left[\sum_m (\quad)_{ai} - \sum_n (\quad)_{ci}\right] dS \quad (2)$$

Application of this general and basic relationship to experimental problems dealing with the elucidation of electrochemical mechanisms[4] is not pertinent to this paper. One such result, however, is qualitatively significant. When corrosion is discussed in terms of local cells with anodic and cathodic areas, cause is often confused with effect. If consideration is limited to metals of good conductivity and to electrolytes also of adequate conductivity, there will be no significant potential difference from place to place along the surface of the metal or in the solution at the low current densities involved in corrosion. At the same time, rates of anodic and cathodic processes occurring simultaneously at any point and, hence, the net current density at that point will vary from place to place if either of the activation energies changes topically. Whether the net local current density is anodic or cathodic is therefore a matter of kinetics and depends on the distribution of activation energies. This may be seen in Equation (3), for a simple two-phase system having a single anodic and a single cathodic process.

$$j_\sigma = Q_c^{\Theta_a} Q_a^{\Theta_c}\left[\left(\frac{I_c}{I_a}\right)^{\Theta_a}\exp\left(-\frac{A_a}{RT}\right) - \left(\frac{I_a}{I_c}\right)^{\Theta_c}\exp\left(-\frac{A_c}{RT}\right)\right] \quad (3)$$

Here, j_σ is a local current density. The Q's contain the various kinetic constants and reactant activities. The Θ's have the form $\Theta_a \equiv \frac{\alpha_a\lambda_a}{\alpha_a\lambda_a + \alpha_c\lambda_c}$ and the I's are

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the activation-energy integrals, as, $I_c = \int_S \exp(-A_c/RT)dS$. The equation means, therefore, that, apart from the factors preceding the brackets, the local current density is determined by both the local activation-energy terms, exp (—A/RT), and the distribution of activation energies over the entire electrode as expressed by the factors $\left(\frac{I_c}{I_a}\right)^{\Theta_a}$ and $\left(\frac{I_a}{I_c}\right)^{\Theta_c}$ Hence, if corrosion rates and the function of inhibitors which act by adsorption at the interface are to be understood, it is necessary to learn how they may affect the two chief variables in the kinetic equations, namely, the activities of the reactants *at* the interface, $a_i^{p_i}$, and the distribution of activation energies for the concurrent processes that may be possible.

The experiments upon which this discussion is based include the XO_4^{n-} ions and molecules derived from most of the transition metals in the periodic system's Groups V to VIII. Among these, $CrO_4^{=}$, $MoO_4^{=}$ $WO_4^{=}$, TcO_4^{-} and OsO_4 have been studied extensively. The perrhenate ion, ReO_4^{-}, and ruthenium (VIII) oxide, RuO_4, failed to inhibit the corrosion of iron and steel and were reduced, with rapid corrosion of the iron. Most of the experimental results from these investigations have been published recently; therefore certain of them will be merely summarized to justify conclusions regarding action of these inhibitors and to demonstrate the great need for more information concerning the details of reaction kinetics in such systems.

Nature of the Inhibited State

Discovery that the pertechnetate ion, TcO_4^{-}, is a strong inhibitor made possible a number of studies on the mechanism of inhibitor action, because of the radioactivity of Tc^{99} and its long half-life, which exceeds 200,000 years. Much of the experimental work to be described, therefore, is based on studies with this inhibitor. Four characteristics of the inhibited state will be discussed, and experimental facts which lead to such characterizations will be indicated.

1. Apparently, when inhibition is as nearly complete as it is with the pertechnetate ion in the absence of appreciable concentrations of electrolytes, the corrosion system is essentially static as far as the metal is concerned. One experiment has been in progress since January 1953 in which a sample of carbon steel (SAE 1010) has remained immersed in an aerated solution containing 5.0 x 10^{-4} f $KTcO_4$. The sample is still bright, and the solution contains no solid matter. Counted repeatedly, the specimen's beta activity has remained constant within counting accuracy after the count became stable early in the experiment. A visible film should have formed in this time if a corrosion current of as much as 4 x 10^{-10} amp/cm² had been flowing.* Since no film is visible, no significant corrosion current is passing, and constant beta activity demonstrates further that there is no continuing consumption of pertechnetate ion. A small amount of inhibitor, reduced at the beginning of the experiment, can be reduced to a smaller quantity if the surface is pretreated to remove active sites.[5]

In other experiments, iron or steel specimens have been inhibited for long periods of time in non-radioactive chromate solutions, but the relatively short half-life of Cr^{51} does not permit such experiments to give the information supplied by the long-term measurements in a pertechnetate solution. The lower oxidation-reduction potential of the pertechnetate couple,[6] as compared with the chromate couple, also favors its use in long-term experiments because there is less tendency for reduction of the inhibitor.

Other evidence of extreme sluggishness of corrosion when inhibition is thorough was found in experiments with osmium (VIII) oxide as inhibitor. Although some initial action occurred with reduction of osmium (VIII) oxide to $Os(OH)_4$, an iron electrode so passivated serves as an indicator for the potential of the osmium (IV-VIII) couple and gives the same potential as a Pt-$Os(OH)_4$ electrode in the same solution.[7] In this case, the passivation is so thorough that there is insufficient anodic dissolution of iron to give detectable polarization of the thermodynamic osmium-couple potential. Therefore, the inhibited system is essentially static in comparison with the magnitude of the exchange current in the osmium (IV-VIII) couple.

2. Although the inhibited state appears to be essentially static as far as dissolution of iron is concerned, the system is dynamic and reversible with respect to the inhibitor. Inhibition is soon lost if the concentration falls below some limiting value.[8] The same conclusion was derived from the effect of added electrolytes on inhibited systems. These studies were of two kinds. First, inhibition by the XO_4^{n-} particles may be destroyed by addition of a certain concentration of ions such as the sulfate ion, which would not be expected to affect the electrochemistry directly. Also, the effect of the added electrolyte could be demonstrated not only by ultimate corrosion but also immediately by observing the electrode potential while adding the electrolyte in increasing concentration.[9] After an electrode acquired a noble and stable potential in an aerated inhibitor solution, sodium sulfate was added in low concentrations. The first additions produced no change in the potential, but a concentration was reached ultimately at which the potential became unstable and began to fall. If the potential was allowed to drop 100 to 200 millivolts and the mixed electrolyte was replaced by pure inhibitor solution, the potential quickly rose to its original value. The rapid changes of potential in both directions were sufficient to indicate that the effects arose from adsorbed and unreduced inhibitor rather than from material precipitated by reduction, because this latter should suffer no change by the addition or removal of sulfate ions. The results indicated also that the adsorbed state is reversible in its dependence upon the relative concentrations of inhibitor and foreign ion. The same type of behavior described for the pertechnetate ion was observed in similar studies with $CrO_4^{=}$, $MoO_4^{=}$, $WO_4^{=}$ and OsO_4.[10] Presently there are no reliable quantitative measurements on the adsorption of these XO_4^{n-} inhibitors, but qualitatively, at least, the evidence justifies the conclusion that the action of them all depends on a reversible, competitive adsorption of the unreduced particle.

3. Much evidence substantiates the theory that atmospheric oxygen is the effective passivating agent when passivation is accomplished by use of the XO_4^{n-} inhibitors in aerated systems. Pick-up of oxygen has been studied by Uhlig and Lord,[11] Berwick and Evans,[12] and McKinnell, Speiser, Fontana and Beck.[13] Other studies show that little chromium goes into the film when chromate is used in aerated solution and even less goes in if the metal is first exposed to air.[14,15] Prior and Cohen[16] showed that, whereas ferrous phosphate forms when phosphate is used in a deaerated solution, the film produced in aerated solution contains very little phosphate. The same result has been obtained with the pertechnetate ion as inhibitor. In aerated solution under favorable conditions, reduction and precipitation of a technetium compound may correspond to as little as 10^{12} atoms/cm², which is considerably less than 1 percent of a monatomic layer.[5]

That oxygen is the effective passivator is shown also by measurements of electrode potentials. $CrO_4^{=}$, $MoO_4^{=}$, $WO_4^{=}$ and TcO_4^{-} raise the potential of electrolytic iron above the Flade, or passivating, potential when used in aerated solution.[10] On the contrary, in deaerated solution, molybdate and tungstate inhibitors gave potentials no higher than the potential in sodium sulfate. These low potentials rose rapidly on admission of air. Even with chromate, which is a strong but sluggish oxidizing agent in weakly acidic solution, the potential in the absence of air is erratic and falls below that assumed in a pertechnetate inhibitor. Furthermore, if a noble potential is first established in an aerated inhibitor solution, the potential falls if oxygen is displaced by nitrogen. These experiments indicate that the passivating interface is formed in all these cases primarily by reduction of oxygen. Only if oxygen is absent or a rapidly reducible inhibitor is used does formation of the interfacial film consume significant amounts of inhibitor by an oxidation-reduction reaction.

4. Films formed by oxygen in the presence of the XO_4^{n-} inhibitors are too thin to be seen, except that the rate of reaction with OsO_4 is initially so fast that the film may grow to visible thickness in a matter of days. Experiments were conducted to determine whether films formed in aerated inhibitor solutions have electrochemical properties like

* Such a current on iron would correspond to a penetration of less than 10^{-3} mpy.

those of passive film formed by more drastic means such as anodic polarization or use of nitric acid. These experiments[17] consisted in maintaining electrolytic iron or low-carbon steel in the aerated inhibitor solution until the potential became constant at a value well above the Flade potential. Sodium sulfate was then added in sufficient quantity to cause the potential to become unstable and fall. Potential-time curves showed that, when the theoretical value of the Flade potential was reached, the rate of fall of potential decreased markedly for a time before proceeding into the region of corrosion potentials.

These experiments were done in solutions containing $CrO_4^=$, MoO_4^-, $WO_4^=$ and TcO_4^-, respectively. In each case, experiments were conducted at several pH values. The break in the potential-time curve for all inhibitors corresponded closely to the value calculated from the known hydrogen-ion dependence of the Flade potential, namely E_f (mv) = 338 — 58.2 pH (referred to the saturated calomel electrode).[18] There are varying theories concerning the nature of the film and the specific electrode process with which the Flade potential is associated.[7,18] It is now clear, however, that drastic and rapid passivation produces a film that is electrochemically the same as that which forms more slowly in aerated inhibitor solutions.

In summary, so far as corrosion is concerned the well inhibited specimen represents an essentially static system in which reversibly adsorbed inhibitor permits oxygen to build a film with the same electrochemical character as that produced under more violent passivating conditions.

The fundamental theoretical problem, therefore, is to determine in what specific way XO_4^{n-} particles enter the kinetics of various electrochemical processes involved. The obvious practical result of their intervention is that whereas oxygen promotes corrosion in their absence, in their presence it becomes a passivator.

Effects of Adsorbed Particles

Many types of experiments demonstrate the profound effect of adsorbed particles upon the behavior of electrons and other charge carriers at surfaces. In certain cases, adsorption is a chemical reaction involving a transfer or sharing of electrons, the only difference between this and ordinary chemical reaction being the limitation of chemisorption to the formation of a superficial product only one molecule thick. In other cases, interaction at the surface may involve a change in the energy state or distribution of charge carriers without the more radical change involved in chemisorption. Such interactions need not have an activation energy themselves but may alter the activation energy of changes involving charge carriers.

Experimental Demonstration of Surface Effects

Adsorption of oxygen on tungsten or other metals increases the work function for removal of electrons; adsorption of cesium lowers it. Adsorption likewise modifies the related property measured in contact potentials. Magnetic susceptibility and electrical resistance of thin metallic films are changed by adsorption in a way which permits a determination whether electrons are donated to the metal by adsorbed particles or are displaced in the direction of these particles. As an example of the change in resistance, adsorption of oxygen or nitrous oxide, N_2O, on a nickel film increases its resistance by removing conduction electrons. Carbon dioxide or water, on the contrary, decreases the resistance of nickel films. When methyl sulfide, $(CH_3)_2S$, is adsorbed on palladium, magnetic susceptibility of the metal is diminished by an amount which indicates that approximately one electron per sulfur atom has been transferred into the d-band of the metal.[20,21]

Many examples could be given of the change in properties of heterogeneous catalysts caused by adding small quantities of a second substance. Such doping of the catalyst may produce marked changes in its activity or its specificity for a particular type of reaction by changing its ability to accept or donate electrons.

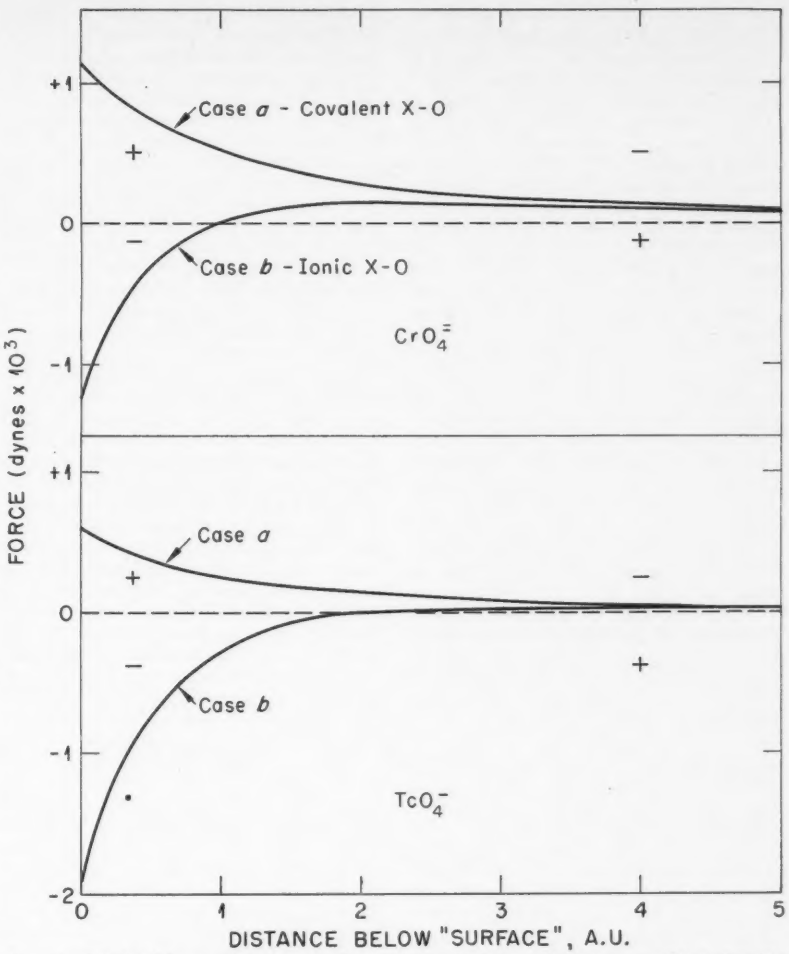

Figure 1—Calculated force acting on an electron under an XO_4^{n-} ion adsorbed on a solid of dielectric constant 1. Plus and minus signs show the polarity of the induced space charge.

Moore and Nelson[22] demonstrated recently the effect of adsorbed $CrO_4^=$ particles on semiconducting properties. Evaporation of a small amount of a solution containing sodium chromate onto the surface of a p-type silicon semiconductor reduced the recombination rate of electrons and positive carriers at the surface by two orders of magnitude. This effect was interpreted as caused by attraction of the chromate ion for electrons so that they are immobilized close to the surface and physically separated from the positive majority carriers with which they otherwise combine. The assumption of this type of electrostatic effect earlier led to the prediction that the pertechnetate ion should be an inhibitor of corrosion.[8,23]

Calculation of the Electrostatic Field

A rigorous calculation of the complete electrostatic effect due to an adsorbed XO_4^{n-} particle is not possible, but a simple treatment will show a possible reason for the specificity of different XO_4^{n-} particles with respect to inhibition. The calculation indicates, for example, that adsorption of two externally similar XO_4^{n-} ions will produce radically different electrostatic effects at an inter-

face if one of them has essentially ionic X-O bonds and the other essentially covalent bonds. Such a calculation was made for the $CrO_4^=$ and TcO_4^- ions.[24] The ion is assumed to be a tetrahedron having reasonably well known dimensions. The ion is considered to be adsorbed with a tetrahedral face in contact with the substrate which, in an inhibited system, will be an oxidized film on the metal. For case a, the net charge of the covalently bonded ion is assumed to be located as a point charge at the center of the tetrahedron. For case b, the X ion is assumed to have a point 6+ charge in the chromate ion and a point 7+ charge in the pertechnetate ion. In case b, the oxygen is given a 2— charge. One may then calculate the electrostatic field normal to the surface and extending into the substrate under the center of the adsorbed tetrahedron. The calculation does not give a quantitative result but shows the differences between the two cases and may indicate semiquantitatively the order of magnitude of the effect. The result of the calculation is shown in Figure 1.

For the covalent model (case a), both chromate and pertechnetate ions induce a positive charge immediately beneath the surface by repulsion of electrons. A sulfate ion would exert an effect approximating that of the chromate ion, if both ions were covalently bonded. In case b, the polar models induce a negative charge close to the surface which then changes to positive a little farther away. In both cases, the effect of a difference in structure seems to disappear at about 5 angstrom units away from the surface. The energy represented by the curves in case b corresponds to some 13 kcal/mole if a dielectric constant of 10 is asumed for the oxidized interphase.

Application to Electrode Kinetics

If the magnitude of this energy is anywhere near realistic, it is sufficient to account for radical changes in any kinetics involving charge carriers at the interface. The effects may be described in a variety of ways. From one point of view, the energy levels in the solid phase are raised or lowered just at the surface as a result of adsorption. From another point of view, the inner potential[25] at the surface is changed by adsorption. The energy changes operate not only on electrons but also on any other participants in the total corrosion process, including protons, metallic ions, lattice defects, oxygen, etc. The corrosion process represents a non-equilibrium state in which microscopic current densities (j_σ in Equation 3) determine the fate of the system, and these current densities themselves depend upon local activities of all requisite reactants, including electrons, and local activation energies for the several partial processes.

Many experimental examples show the effect of foreign substances upon electrode processes. Evidence substantiates the theory that inhibiting chromate and non-inhibiting sulfate ions, for instance, differ greatly in the degree of polarity of their X-O bonds.[24] Figure 1 indicates that the sulfate ion, if its bonds are essentially covalent, can induce only a space charge like that shown in case a for the chromate ion. Since the sulfate ion does not inhibit, it would appear that the reverse space charge shown for case b is requisite for inhibition. Unfortunately for any attempt at a detailed interpretation of such a space charge effect, there are several ways in which it may enter into the kinetics at the interphase. For corrosion to proceed, passage of cations from the metallic lattice into the film or solution must be balanced by reduction of either oxygen, protons or water. Experiments on the passivation of stainless steel in dilute sulfuric acid have demonstarted that passivation by dissolved oxygen is possible as soon as the potential rises to the approximate value of the hydrogen electrode potential.[26] This suggests the possibility that, with iron or carbon steel, the inhibitor effectively hinders reduction of protons, in comparison with the passivating reduction of oxygen.

Such an effect could arise, in part, by reduction in the availability of electrons at the interphase, due to their attraction and shielding by the adsorbed inhibitor. On the solution side of the interphase, electrostatic polarization by the inhibitor particle may increase the energy required for a proton to penetrate to the surface. Both of these results of electrostatic polarization would have the effect of increasing the activation energy for the cathodic reduction of hydrogen ions. Any effect on the activation energy for reduction of oxygen molecules should be less, because of their neutrality and also because, in all probability, they share with inhibitor particles in competitive adsorption on the surface.

Electrostatic effects may operate also on other charge carriers involved in the over-all corrosion process, such as metallic ions, lattice defects and hydroxide ions. For example, corrosion of iron at a given potential in absence of oxygen proceeds faster in alkaline solution than in acid solution.[27] Bonhoeffer and Heusler[28] have attempted to interpret this in terms of a reduction of energy required for the anodic process. If this explanation is correct, preferential adsorption of an XO_4^{n-} inhibitor would displace the hydroxide ions (or water molecules) and raise the activation energy for dissolution.

Of the many possible effects of the inhibitor on different processes involved in corrosion, there is not enough information at present to decide which is most important. It is apparent though, that electrostatic interactions at the interphase must be taken into account in any attempt to understand inhibitor action. Similar effects in catalysis and in the properties of semiconductors are established so well that their relevance to problems of inhibition can scarcely be questioned. For their explicit interpretation, however, more information must be gained regarding chemical and electrical properties of the interphase between a metal and its corrosive environment.

References

1. S. Glasstone, K. J. Laidler and H. Eyring. The Theory of Rate Processes. McGraw-Hill Book Co., New York, 1941, pp. 552 ff.
2. H. Gerischer. *Z Elektrochem,* 59, 604 (1955); K. J. Vetter. *Z Elektrochem,* 59, 596 (1955); J. O'M. Bockris. Modern Aspects of Electrochemistry. Butterworths Publications Ltd., London, 1954, pp. 180 ff.
3. Franz A. Posey. *J. Electrochem Soc.,* 106, 571 (1959).
4. For an example, see Franz A. Posey, G. H. Cartledge and R. P. Yaffe. *Ibid,* 106, 582 (1959).
5. G. H. Cartledge. *J Phys Chem,* 59, 979 (1955).
6. G. H. Cartledge and Wm. T. Smith, Jr. *J Phys Chem,* 59, 1111 (1955).
7. G. H. Cartledge. *J Phys Chem* 60, 1571 (1956).
8. G. H. Cartledge. *Corrosion,* 11, 335t (1955).
9. G. H. Cartledge. *J Phys Chem,* 60, 28 (1956).
10. R. F. Sympson and G. H. Cartledge. *J Phys Chem,* 60, 1037 (1956).
11. H. H. Uhlig and S. Lord. *J. Electrochem Soc,* 100, 216 (1953).
12. I. D. G. Berwick and U. R. Evans. *J. Applied Chem,* 2, 576 (1952).
13. Wm. T. McKinnell, Jr., Rudolph Speiser, M. G. Fontana and F. H. Beck. *Z. Electrochem,* 62, 773 (1958).
14. J. E. O. Mayne and M. J. Pryor. *J Chem Soc,* 1831 (1949).
15. D. M. Brasher and C. P. De. *Nature,* 180, 28 (1957).
16. M. J. Pryor and M. Cohen. *J Electrochem Soc,* 98, 263 (1951); M. J. Pryor, M. Cohen and F. Brown. *Ibid.,* 99, 542 (1952).
17. G. H. Cartledge and R. F. Sympson. *J Phys Chem,* 61, 973 (1957).
18. U. F. Franck. *Z Naturforschg,* 4a, 378 (1949); K. J. Vetter. *Z Physik Chem,* 202, 1 (1953).
19. E. Lange. *Naturwissenschalten,* 43, 12 (1956); E. Lange and H. Göhr. *Z Elektrochem,* 61, 1291 (1957); K. J. Vetter. *Ibid,* 62, 642 (1958); G. H. Cartledge. *Ibid,* 62, 684 (1958).
20. M. H. Dilke, D. D. Eley and E. B. Maxted. *Nature,* 161, 804 (1948).
21. For reviews of these subjects see: J. E. Germain. *Bull Soc Chim,* 1305 (1956) and R. Suhrmann. *Z Elektrochem,* 60, 804 (1956).
22. A. R. Moore and Herbert Nelson. *RCA Review,* 17, 5 (1956).
23. G. H. Cartledge. *J Am Chem Soc,* 77, 2658 (1955).
24. G. H. Cartledge. *Z Elektrochem,* 62, 684 (1958).
25. E. Lange. *Z Elektrochem,* 55, 76 (1951).
26. G. H. Cartledge. *J Electrochem Soc,* 104, 820 (1957).
27. B. Kabanow, R. Burstein and A. Frumkin. *Disc Faraday Soc,* 1, 264 (1947).
28. K. F. Bonhoeffer and K. E. Heusler. *Z Elektrochem,* 61, 122 (1957). According to a personal communication from K. E. Heusler, precise polarization measurements show that the difference in anodic current between acid and alkaline solutions is actually much greater than that reported by the Russian authors. See also K. E. Hensler. *Z Elektrochem,* 62, 582 (1958).

Any discussion of this article not published above will appear in the December, 1959 issue

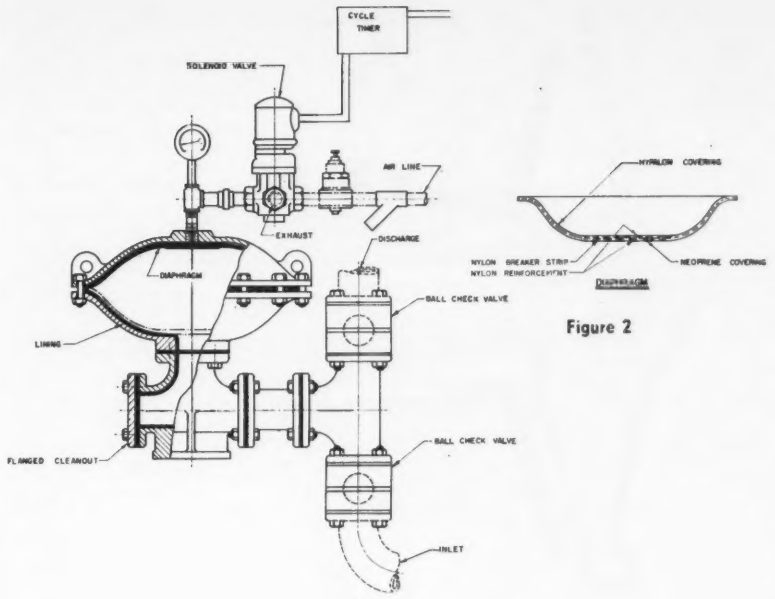

Figure 1

Figure 2

Abstract

Of the pumps used in the chemical and allied industries, about 90 percent are of the centrifugal and diaphragm types. These pumps are required to handle corrosive liquids under conditions of high pressure and high temperature, expensive or hazardous liquids where leakage to atmosphere cannot be tolerated, liquids with solids in suspension, often of an abrasive nature, creating both a corrosion and abrasion problems and extremely corrosive liquids which may be radioactive. Diaphragm type pumps have certain advantages over centrifugal pumps for severe chemical applications because there is no shaft sealing problem, solids in suspension can be handled at relatively low velocities and a high degree of corrosion resistance can be obtained by the use of high alloy steels for the pump body and synthetic materials for diaphragms. Packingless pumps include the so-called canned-motor centrifugal pump in which the pump impeller is mounted on the same shaft as the rotor. Both the rotor and the stator are sealed from the fluid by corrosion resistant cans or shields and the rotor moves in the liquid being pumped. The rotor-impeller shaft is supported on sleeve type bearings submerged in the liquid pumped. Canned-motor pumps usually cannot be applied where the liquid contains solids because of close clearances and possibility of damage to bearings by abrasion.

Designs giving longer service life in the conventional centrifugal pump usually include the following: Improved sealing devices where the pump shaft passes through the casing, new alloys or metals for the wetted end to provide a better corrosion resistance, improved elastomers, plastics and ceramics which permit lining entire pumps for a high degree of corrosion resistance. Improved shaft seals are discussed along with a study of new materials available for pump parts, and linings for pumps commonly used in chemical pumping service. 7.3

Design and Materials for

Reduced Pump Corrosion*

By JACK E. PICCARDO

Introduction

OF THE PUMPS used in the chemical and allied industries, about 90 percent are of the centrifugal and diaphragm types. These pumps are required to handle: (1) Corrosive liquids under conditions of high pressure and high temperature; (2) Expensive or hazardous liquids where leakage to atmosphere cannot be tolerated; (3) Liquids with solids in suspension, often of an abrasive nature, creating both a corrosion and an abrasion problem; (4) Extremely corrosive liquids which may be radio-active.

When several of these conditions are combined the design and construction of suitable pumping equipment presents interesting and complex problems. In practice, it is extremely difficult to completely eliminate corrosion, erosion, fatigue and simple wear, but ways have been found to slow down these destructive forces. By proper design and choice of materials of construction, it is possible to increase pump service life, reduce maintenance costs and minimize plant downtime.

Types of pumps to be considered here will be classified in two groups: (A) Seal-less pumps, and (B) Pumps with packing gland or mechanical seals.

Advantages of Diaphragm Type

Diaphragm type pumps have certain advantages over centrifugal pumps in severe chemical applications because there is no shaft sealing problem, solids in suspension can be handled at relatively low velocities and a high degree of corrosion resistance can be obtained by the use of alloy steels or lined castings for the pump body and synthetic rubbers for the diaphragms. Figure 1 illustrates an air operated diaphragm pump with ball check valves. This type of pump has found wide application in the chemical pumping field. The body and check valves can be made of stainless steel, but for many applications iron or steel castings are used with rubber or plastic linings. Some of the common materials used for lining of the castings are chlorosulfonated polyethylene rubber, polychloroprene, butadiene-styrene rubber and polyvinylchloride. These linings are suitable for operation in the temperature ranges of 140 to 225 F, depending on the material. For temperatures in the range of 250 to 400 F, it is necessary to provide other materials, such as hexafluoropropylene-vinylidene fluoride, polychlorotrifluoro ethylene or polytetrafluoroethylene. Silicone compounds and plastics, such as polybischloromethyloxetane, can also be used as linings for the higher temperature conditions.

The critical working parts of a pump of this type are the diaphragm and check valves. As shown in Figure 2, a special diaphragm construction can be provided using three different types of material. The chlorosulfonated polyethylene layer provides the necessary chemical resistance, the nylon cloth provides tensile strength, and the polychloroprene layer provides flexure and resiliency. Diaphragms usually can be made of the same material normally used for pump linings. However, it has not yet been possible to make satisfactory pump diaphragms of fluorocarbons with proper strength and flexure characteristics. Recent developments indicate that it may be possible to bond fluorocarbons to other materials which will provide the necessary flexure and tear strength.

Check valves are important in the diaphragm pumping unit. These valves can be of the ball, poppet, or pinch type. For slurry application, the ball and pinch

About the Author

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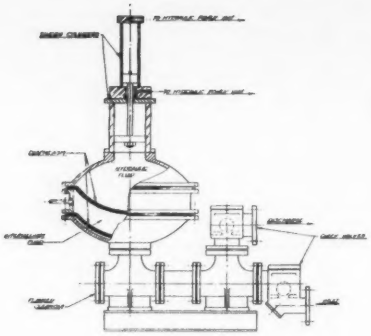

Figure 3

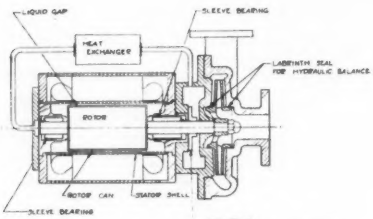

Figure 4

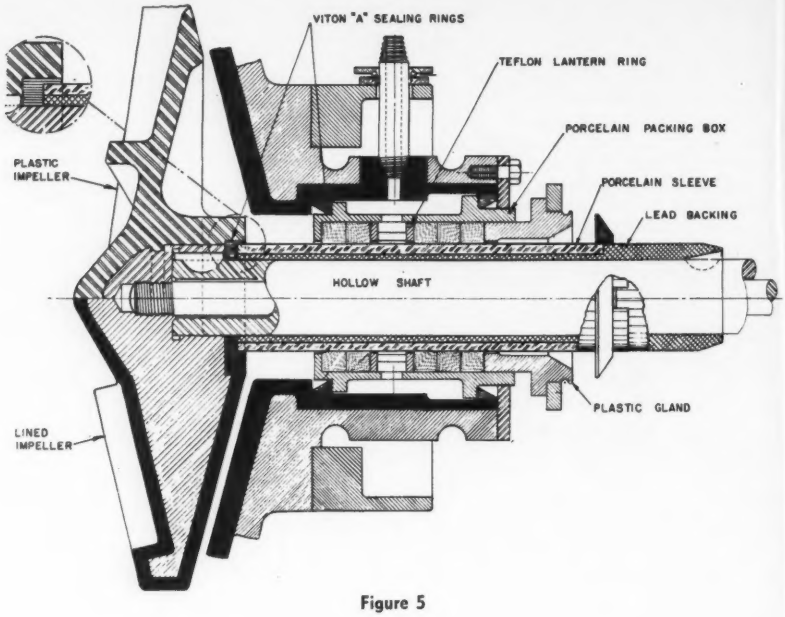

Figure 5

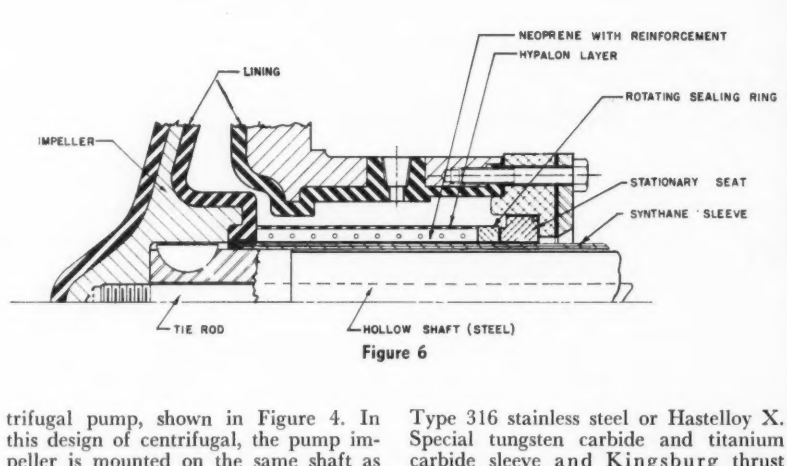

Figure 6

types give the best service. Both types lend themselves to the use of synthetic rubber parts or linings. For some applications the valve bodies are made of Type 316 stainless steel and the balls of stainless steel, porcelain, or cast iron with rubber lining. Replaceable valve seats can be provided of similar materials.

Where hazardous, radioactive or expensive liquids are being handled, a hydraulically operated diaphragm pump is recommended. Figure 3 illustrates a pump of this type with double diaphragm construction. A compatible or neutral liquid is provided between the primary and secondary diaphragms. In the event of failure of the main diaphragm, there is no loss of fluid and the pumping system continues to function. Means can be provided for detecting the diaphragm failure when it occurs and repairs can be made when convenient.

Air operated diaphragm pumps do not have balanced pressures acting on the diaphragm. For this reason their use is limited to discharge heads of 100-150 psi. For higher operating pressures it is advisable to balance the pressures on the diaphragm and this can be done with the hydraulically actuated unit using either single or double diaphragm construction. In nuclear reactor service, hydraulically actuated diaphragm pumps have been developed as feed pumps supplying small quantities of slurry at 2,000 psi. Where the capacity is small, specially designed stainles steel diaphragms can be provided which permit operation at temperatures above 400 F.

Canned-Motor Type Centrifugal

Also classed with diaphragm seal-less type pump is the "canned-motor" centrifugal pump, shown in Figure 4. In this design of centrifugal, the pump impeller is mounted on the same shaft as the conventional rotor. Both the rotor and stator are sealed from the fluid by corrosion resistant cans or shields, and the rotor rotates in the liquid being pumped. The rotor-impeller shaft is supported on sleeve type bearings, which are submerged in the liquid pumped. Canned-motor pumps usually are not applied where the liquid contains a large percentage of solids, because of close clearance and the possibility of damage to the bearings by abrasion. For most chemical service applications the pump sleeve bearings are made of carbon and the shields or cans of stainless steel.

Canned-motor centrifugal pumps have been developed in large sizes, up to 700 horsepower, for handling molten sodium and sodium-potassium mixtures in nuclear power plants. These units have been designed to operate at temperatures between 1,000 and 1,400 F. Motor windings normally are conventional Class "H" insulation and the cans or shields are made of .020-inch Inconel sheets, which are rolled and seam welded into cylinders. Pump wetted parts are usually of Type 316 stainless steel or Hastelloy X. Special tungsten carbide and titanium carbide sleeve and Kingsburg thrust bearings have been developed because of their wear resistance and compatibility with sodium. Elaborate heat exchangers are provided for dissipating the heat within the motor itself and for cooling the bearings.

Pumps With Packing Gland or Mechanical Seals

This classification includes the various types of centrifugals, such as single stage, multistage, double suction and reverse suction. In all of these constructions it becomes necessary to seal the rotating shaft against loss of liquid to atmosphere. This problem becomes more critical with a mixture of corrosive liquid and abrasive solids at high pressures. To provide maximum service life in these types, particular consideration has been directed toward: (1) Improved sealing devices where the pump shaft passes through the casing; (2) New alloys or metals for the wetted end, which will provide greater corrosion resistance; (3) Improved elastomers, plastics and ceramics, which will permit lining entire pumps

to provide a higher degree of corrosion resistance.

In recent years advances have been made in both packing gland and mechanical seal construction. Concurrent with improved designs, new materials have been used for improved corrosion resistance. Figure 5 illustrates an advanced design of packing gland incorporating several materials for maximum corrosion resistance. This particular assembly includes a porcelain packing box with porcelain shaft sleeve, fluorocarbon lantern ring, and porcelain or plastic gland. Sealing rings are made of hexafluoropropylene-vinylidene fluoride. When necessary, reinforced fluorocarbon parts can be substituted for the porcelain. The impeller is usually made of plastic, such as phenol formaldehyde, or of metal with rubber lining.

Figure 6 illustrates a similar type of pump with mechanical seal. There are no metal parts in this seal and the construction is such that the liquid is not in contact with the shaft of the pump. An inexpensive reinforced phenol formaldehyde shaft sleeve is provided to protect the shaft in case of seal failure. A polychloroprene compression sleeve replaces the conventional spring of the mechanical seal and maintains the proper pressure on the sealing faces of the seal. A carbon sealing ring is bonded to the sleeve and a stationary carbon or ceramic ring provides the mating part. For some applications where the use of polychloroprene may be limited because of chemical attack or temperature, it has been possible to develop a compression sleeve consisting of a layer of polychloroprene, plus a layer of Chlorosulfonated polyethylene. Mechanical seal compression sleeves can also be made of butadiene-styrene rubber, hexafluoropropylene-vinylidene fluoride, and other materials.

When pumping slurries of an abrasive nature, a difficult sealing problem arises with packing glands. Double mechanical seals usually are recommended along with other special designs. Figure 7 illustrates a stainless steel pump with double seals designed to handle abrasive slurries. In this construction the pump discharge pressure has been removed from the stuffing box and it is necessary only to seal the suction head, which, in many cases, does not exceed 20 feet. A special expeller has been provided to keep the abrasive particles away from the mechanical seal. Because the expeller also excludes liquid from the seal faces, it is necessary to provide external cooling, which can be done by circulating water in and out of the stuffing box.

The wetted parts of the pump itself, namely impeller, casing, and cover, can be made of several types of corrosion resistant materials. The most commonly used materials are Type 316 stainless steel and Carpenter 20 stainless steel. Where a higher degree of corrosion resistance is required, there are available other alloys, such as Hastelloy, as well as titanium and zirconium. While these are extremely good materials from a corrosion standpoint, they usually are too expensive for the average application.

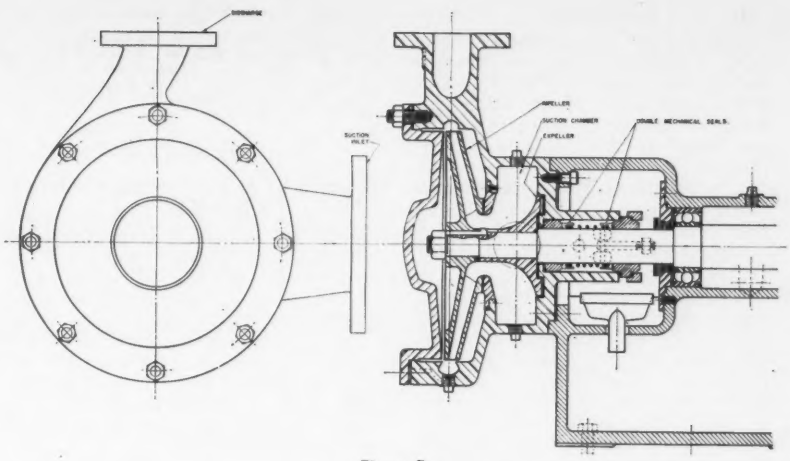

Figure 7

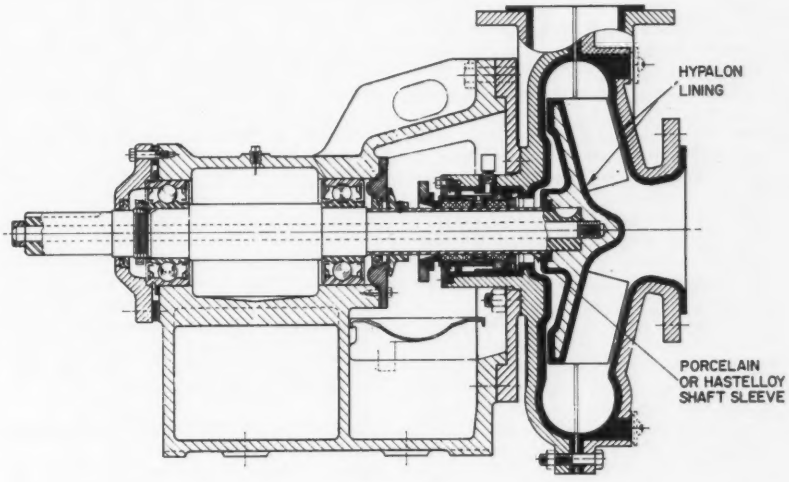

Figure 8

For example, titanium provides excellent resistance to salt water, acids and many chemicals, and combines high strength with light weight. It also maintains its mechanical properties at temperatures up to 900 F. It is difficult to cast and requires melting in a vacuum or inert atmosphere. Special molds machined from solid graphite are required for casting purposes. As a comparison, a pump impeller normally costing $150 when made of Type 316 stainless steel would cost about $400 made of titanium.

Fortunately corrosion resistance does not depend on metallurgy alone. Other materials, such as synthetic rubbers, plastics, porcelain and carbon, which are becoming widely used as materials for pump construction, also are available. The chemical industry has for a number of years had satisfactory experience with many synthetic rubbers and plastics as linings for casings and impeller in centrifugal pumps. To this list has recently been added chlorosulfonated polyethylene. This has permitted pump linings to operate at higher temperature limits with greater resistance to chemical attack.

Figure 8 illustrates a chlorosulfonated polyethylene lined centrifugal pump with special packing gland previously described. There is no metal in contact with the liquid when it is equipped with a porcelain shaft sleeve. A hollow shaft with the tie rod permits fastening of the impeller without use of impeller locknut. The same lined casing also can be provided with stainless steel impeller or all plastic impeller. Linings of polyomylchloride, polybischloromethyloxetane, and glass are now in the process of development and will be available in the future.

Pumps with the wetted end made of porcelain or carbon also are finding applications in chemical pumping service. Because these materials cannot be subjected to shock loads and rough handling, it usually is best to provide a metal frame for enclosing the casing parts. Porcelain offers good corrosion resistance over a wide range of temperatures, but cannot be subjected to thermal shock loads created by extreme temperature differences. Carbon parts, on the other hand, are not affected by thermal shock and may be operated at temperatures up to 340 F.

Conclusions

1. Diaphragm type pumps have a definite field of application in the chemical and process industries. The canned or sealed construction of the diaphragm pump permits the handling of slurries and highly corrosive liquids at temperatures up to 400 F. By the proper choice of materials for diaphragms, pump casing and check valves, it is possible to handle slurries which normally cannot be handled satisfactorily by any other type of pump.
2. The canned motor centrifugal pump can be designed to operate at extremely high temperatures and has the advantages of zero leakage and low maintenance when pumping corrosive liquids or metals. It can be mounted in any location in the system, which makes it an ideal component for liquid metal systems, such as used in the nuclear power field.
3. The centrifugal pump shaft sealing problem can be minimized by the use of a reversed suction design in combination with double mechanical seals. This construction lends itself to applications where both corrosion and abrasion are a factor.
4. Improved packing gland and mechanical seal constructions have been developed which isolate the corrosive liquids from the pump shaft and reduce or eliminate shaft leakage in the centrifugal pumps. The required corrosion resistance can be provided by the proper choice of materials for the stuffing box or seal parts.
5. The pump designer of today has a wide choice of corrosion resistant metals which permit centrifugal pump operation at high temperatures and pressures. For the lower temperature ranges plastic, glass and synthetic rubber linings are available which provide satisfactory corrosion resistance under most operating conditions. With the proper skill and ingenuity the designer can select and combine these materials to obtain the widest coverage and maximum corrosion resistance.

Bibliography

Norman S. Mott. Basic Principles of Corrosion, and Factors Affecting Corrosion. *Technical Topics*. Cooper Alloy Corp., Hillside, N. J.

R. B. Norden. Corrosion Forum. *Chem. Eng.*, 1958 (Dec.).

W. M. Wepfer. Guide to the Selection of Canned Motor Pumps. Preprint No. 77, American Institute of Chemical Engineers, New York 36, N. Y.

Charles H. Gabbard. Diaphragm Feed Pumps for Homogeneous Reactors. Preprint No. 74, American Institute of Chemical Engineers, New York 36, N. Y.

F. R. Drahos. Right Material Cuts Pump Corrosion, *Chem. Eng.*, 1958 (March).

Oliver P. Steele. High Temperature Mechanical Canned-Motor Liquid Metal Pumps. Preprint No. 76, American Institute of Chemical Engineers, New York 36, N. Y.

DISCUSSIONS

Questions by A. V. Morrison, California Oil Co., Perth Amboy, N. J.:

1. What type of hard or resilient coating would you recommend for a 3-foot diameter, 500 RPM, 40,000 gpm salt water pump to overcome cavitation and stress corrosion cracking?
2. What specific coating materials would you consider for such a pump, the cost of the coating being insignificant in relation to the cost of the impeller?
3. What advances have been made in the elimination of cavitation?

Replies by J. E. Piccardo:

1. What type of hard or resistent coattion within the fluid and cannot be overcome by use of different materials of pump construction. The best remedy for this condition is design of the pump with proper velocity distribution particularly at the suction inlet of the impeller.

2. For salt water application a plastic hard coating would be satisfactory on clean liquid. If the liquid contains sand or other abrasives a natural or synthetic rubber lining may be advisable.

3. Improved hydraulic design of centrifugal pumps has contributed most towards elimination of cavitation. It has also been found that by operating the pump at the most efficient point on the head-capacity curve, cavitation erosion can be reduced because flow through the impeller is more uniform.

Question by R. McFarland, Carpentersville, Ill.:

What is chemical and erosion effect on open type Hypalon lined pumps at high pump speeds of 3500 rpm?

Replies by J. E. Piccardo:

With higher pump speeds of 3500 rpm, the fluid velocities are also higher, thereby accelerating chemical and erosion attack.

Question by R. J. Law, The International Nickel Co. of Canada, Ltd., Toronto:

Have cases been encountered where carbon or graphite packing caused galvanic corrosion of stainless steel shafts?

Reply by J. E. Piccardo:

We are not familiar with any cases where galvanic corrosion of a stainless steel shaft was caused by carbon or graphite packing. However, we do know that lead or babbit are sometimes introduced into graphite mixtures for shaft lubrication purposes. With the proper electrolyte there may be established a galvanic action between the lead and one of the elements in the stainless steel shaft which would result in shaft pitting or corrosion.

Question by John M. Clarke, Chicago, Ill.:

What is the pressure limitation of the Kel-F, PVC, Teflon type diaphragms?

Reply by J. E. Piccardo:

Pressure limitations for Kel-F, PVC, and Teflon diaphragms are approximately 400 psi with hydraulic balance across the diaphragm. As indicated in my paper, Kel-F and Teflon are poor diaphragm materials from the standpoint of flexure life. PVC on the other hand can be molded with reinforcement and satisfactory flexure life can be obtained.

Remarks by Lewis W. Gleekman, Wyandotte Chemical Corp., Wyandotte, Mich.:

Mr. Piccardo's remarks about the relative costs of titanium and stainless pump impellers were of great interest, particularly in view of Wyandotte's experience in a similar matter. What was missing, unfortunately, was the comparison of annual costs of one pump material versus another, rather than merely the first cost comparison. For example, a 9-inch 6-bladed open impeller welded from Hastelloy C cost $150 (materials and labor) while the same impeller made from titanium cost $390. However, the Hastelloy C impeller had to be repaired every 90 days at a cost of $90 and had to be discarded at the end of one year. The annual cost of this impeller then was $420. After 3½ years the titanium impeller in the same solution under the same operating conditions was in excellent condition, certain to reach the 10 year predicted life. Its annual cost then was $39. The comparison is obvious: $39 per year versus $420 per year.

Any discussion of this article not published above will appear in the December, 1959 issue

Corrosion Processes in Carbonated Beverage Cans*

By E. L. KOEHLER, J. J. DALY, Jr., H. T. FRANCIS and H. T. JOHNSON

Abstract

Describes work undertaken to minimize occurrence of perforations and excessive iron pick up in carbonated beverage cans. Corrosion mechanism was one of attack on steel base of cans stimulated by reduction processes occuring at areas of exposed tin or other cathodic regions. Best solution was limiting galvanic current in the can through reducing corrosivity of beverage and control of metal exposure in the can. Short time test methods were devised to evaluate beverage corrosivity. A low air content was essential and control over other depolarizers in beverage led to lower corrosivities. Improvements made in organic coating systems and metal exposure in the side seam and double seam regions reduced corrosion currents so that perforations were no longer a problem and so that iron pick up was effectively reduced. 8.3.2

Introduction

CARBONATED BEVERAGES comprise a wide range of products that vary markedly in their degree of corrosiveness when packed in metal containers. Early attempts to pack carbonated beverages in cans were technically unsuccessful. Results such as container perforation and iron pickup in the product led to the realization that controlling corrosion processes were different than those found in other acid foods and that a special type of metal container was required for carbonated beverages.

In preliminary development, carbonated beverages were test packed in special tin plate cans to determine interaction between product and container over a normal storage time. These test packs were extremely useful but time consuming, requiring lengthy storage periods (even under accelerated storage conditions) for data to accrue. The following observations were made during periodic examinations of these preliminary test packs:

(1) Perforations tended to be concentrated near the shelf end double seam regions of the can although they could possibly occur anywhere.

(2) Hot-dip tin plate usually showed less iron pickup than the electrolytic, but it was not known if tin plate was any better from the standpoint of perforations.

(3) Occluded air in the beverage and the can's head space appeared to accelerate corrosion, but the exact effect was uncertain because of complicating variables.

(4) Use of a more impervious organic coating system on the can interior increased its shelf life up to a point, at least, but its exact effectiveness was not known.

Helpful as these indications were, precise information was needed relative to specific mechanisms involved and their control. Studies reported in this article were undertaken to secure this information by determining the following:

1. Corrosion mechanism in a carbonated beverage can.
2. Corrosiveness of various carbonated beverage products.
3. Effectiveness of organic protective coating systems.
4. Influence of base steel.
5. Influence of tin thickness and structural features.

★ Submitted for publication April 6, 1959. A paper presented at a meeting of the 15th Annual Conference, National Association of Corrosion Engineers, March 16-20, 1959, Chicago, Ill.

Corrosion Mechanism in Cans

Early experience showed that tin normally assumed a potential cathodic to steel; therefore, the corrosion mechanism encountered in carbonated beverage cans was probably galvanic. This was partially verified by the fact that the gross rate of attack on black plate by beverages was not high enough to account for the rate of perforations observed in test packed cans. These findings established that perforations in cans at areas of exposed steel were stimulated by reduction processes occurring elsewhere on the can interior.

Tests were conducted by externally coupling tin and steel electrodes in a closed test cell using air-free uncarbonated cola as the test medium. Both metals were waxed off so that 7 sq mm of tin were coupled with 0.1 sq mm of black plate. The test cell was then flushed with oxygen-free nitrogen. After 24 hours the current was recorded and the cell flushed with oxygen. Test results are presented in Table 1.

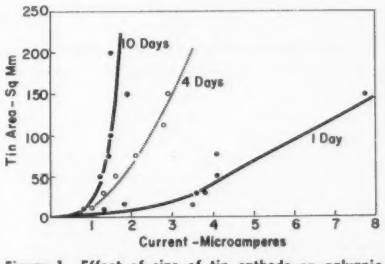

Figure 1—Effect of size of tin cathode on galvanic current. Carbonated cola with air content of 5 cc per 12-ounce bottle was used.

In all data obtained, steel was the anode (region of metallic attack). Readings for air-free cola under nitrogen indicated that some depolarizer other than oxygen must be active to allow the indicated galvanic current to flow. Admission of oxygen, a strong depolarizer, caused considerable stimulation in the galvanic current recorded.

By calculation, magnitude of the galvanic currents would result in perforation of the sheet in 30 days if concentrated at a pit 1 mm in diameter. After 14 days, tests of the tin-steel couple resulted in a 1 mm pit half-way through the 0.010-inch sheet.

These results confirm that corrosion in the carbonated beverage cans is galvanic in nature, with dissolution of metal at areas of exposed steel stimulated by reduction processes occurring at areas of exposed tin or other cathodic regions existing in the can.

Corrosivity of Product

Appropriate electrodes were designed to measure the galvanic current flowing between a steel and tin electrode; this measurement was used as an index of the beverage's corrosiveness. Factors considered in the design of test electrodes included (1) size of the tin cathode, (2) size of the steel anode and (3) proximity of the tin and steel.

In evaluating these factors, carbonated cola with an air content of 5 cc per 12 ounce bottle was used as the electrolyte. Tests showed that the steel area exposed and proximity of the tin and steel made little difference. The effect of area of tin is shown in Figure 1.

TABLE 1—Effect of oxygen on galvanic current between small area of steel coupled to relatively large area of tin (steel anodic) in de-aerated, uncarbonated cola at 25 C.

	Galvanic Current-Microamperes
Before O_2 admitted (N_2 flushed, 24 hr)	1.05
1½ hr after admitting O_2	7.9
11 days after admitting O_2	3.3

Daly

Francis

Koehler

H. T. Johnson

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HAROLD T. JOHNSON is a chemical engineer in the Metal Research and Development Division of Continental Can Co., Chicago. His work involves electrochemical corrosion in metal containers. He received a BS in chemical engineering from Illinois Institute of Technology and is author of several papers on corrosion of canned carbonated beverages.

The corrosion process was under cathodic control or dependent upon how fast the depolarizers present could diffuse to the tin surface. In the first few days of the test, while concentration gradients were being established, the current was rather sensitive to area. However, after a few days, any change in area above a certain area of exposed tin made little difference. Since a test time of one or two days was desired, careful selection of the proper tin cathode size for the test electrode was necessary because the exposed tin area would exert an influence. Thus cathode size was selected which gave currents of a magnitude conveniently translatable into estimated pack performance and provided a definite indication of any differences in corrosiveness.

Figure 2 shows two types of electrodes developed. Tin wire and steel black plate were mounted in epoxy resin. Wire leads extending from the tin and steel were

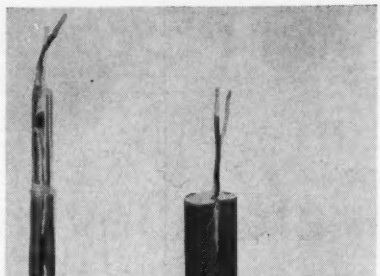

Figure 2—Tin-steel couple electrodes used in tests. A is two views of bottle electrode; B is corrosivity test electrode.

coupled externally through a device of sufficient sensitivity and low resistance to measure galvanic current produced. This type electrode is advantageous because the end can be reground after each use to exposed fresh areas of tin and steel.

Electrode A in Figure 1 was designed for use in bottled beverages. Though of value in certain applications, this electrode does not give a satisfactory corrosiveness rating because of the small area of exposed steel. Thus electrode B was designed. Results using this type of electrode and its comparison with pack performance have been reported.[1,2]

Many beverages were tested, but discussion here will be limited to a few exhibiting typical variations in behavior. Preliminary tests with Electrode A immersed in bottled cola showed the galvanic corrosion current to be under cathodic control. With other beverages such as orange, control was mixed. Tests also showed that, though carbonation had some influence on the current flow, effects were negligible. This simplified testing, precluding the necesssity for further work on effects of carbonation.

Figure 3 shows a typical cathodic polarization curve for a tin cathode in a carbonated beverage. The current equivalent to the limiting rate of diffusion of depolarizers to the cathode surface is designated as cathodic capacity of the beverage. Curve 1 is similar to the anodic polarization curve for the

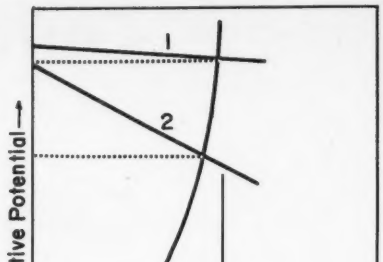

Figure 3—Relationship between cathodic capacity and measured galvanic current for various types of anodic polarization curves.

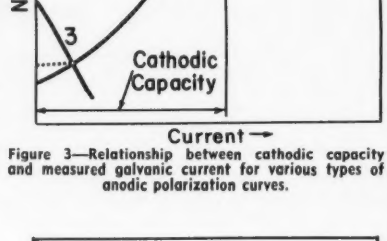

Figure 4—Effect of increasing anode size by factor 10 on anodic polarization curve (Area b = 10 x Area a) and measured galvanic current.

steel anode of the bottle electrode (Figure 2A) in cola. The type polarization curve in orange with the bottle electrode is indicated by Curve 3 and with the corrosivity test electrode (Figure 2B) by Curve 2. With the bottle electrode, galvanic current (the current at the intersection of the anodic and cathodic polarization curves) appeared to be greater in cola (Curve 1, Figure 3) than in orange (Curve 3, Figure 3).

However, pack tests showed orange to be extremely corrosive and more likely

TABLE 2—Relationship Between Galvanic Couple Current and Cathodic Capacity

Beverage	Flushing Gas	Current—Microamperes			
		Bottle Electrode		Corrosivity Test Electrode	
		Couple Current	Cathodic Capacity	Couple Current	Cathodic Capacity
Grape	Nitrogen	0.6	1.6	1.1	1.3
Grape	Air	0.6	2.8	6.5	8.5
Orange	Nitrogen	0.1	0.9	0.4	1.1
Orange	Air	0.4	>4.5	3.5	>6
Cola	Nitrogen	0.6	0.9	0.8	1.0
Cola	Air	2.2	2.4	3.9	4.1

to cause perforations than cola. Thus galvanic currents with the bottle electrode did not provide a good rating of the relative corrosiveness of these products. Suppression of the anodic polarization curve in orange is evidently due to an anodic corrosion inhibitor. Suppression of the anodic polarization curve in an electrode system designed to evaluate the corrosiveness of a beverage from a perforation standpoint is not wanted. To conform, the test electrode ideally should give an indication of the cathodic capacity of the beverage. With anodic polarization Curves 1 or 2, the galvanic current reading closely represented the cathodic capacity, but with anodic polarization Curve 3, it did not.

As illustrated in Figure 4, with the anode size ten times as large, an anodic polarization Curve b is obtained in which the polarization rate is only 1/10 that of Curve a. With such an anode, the galvanic current measurement bears a useful relationship to the cathodic capacity of the beverage. Therefore, in the corrosivity test electrode, the steel area was made large to obtain a rather flat anodic polarization curve even in such a medium as orange.

Although effect of an anodic inhibitor on the steel is not completely eliminated, the reading represented a realistic compromise to the extent that tests were concerned with iron pickup in the beverage and with perforations. Such anodic inhibition can be expected to affect iron pickup. Data illustrating the relationship between cathodic capacity and galvanic current, as determined with the bottle and test electrodes in various beverages, are presented in Table 2.

Figure 5 shows the effect of oxygen on galvanic current flow. Azo type food dyes such as amaranth act as depolarizers and change the current produced.[3] The effect of amaranth on current flow is illustrated in Figure 6. In both cases, increased oxygen or azo type dyes would be expected to result in increased product corrosiveness in the can.

The corrosivity test rating does not indicate directly the galvanic current which will flow in a beverage can; however, it does provide an index of the product's corrosiveness. From Faraday's law, calculations indicate that a continuous current flow of 0.04 μa in a beverage can for 1 year will raise the iron content 1 ppm in 12 ounces of beverage. To cause a can perforation through 0.010-inch plate in a year's time, a current flow of 0.2 μa concentrated at an assumed pit size of 1 sq mm would be required.

Current flow in the corrosivity test is of a high magnitude compared with that which an organic coated beverage can is capable of supporting. Thus beverages with considerably higher corrosivity ratings than 0.2 μa can be safely tolerated because commercial beverage cans are designed for optimum corrosion resistance and because packing procedures are controlled to minimize beverage corrosiveness.

Effectiveness of Organic Coating Systems

Organic protective coatings in carbonated beverage cans are approximately 0.001-inch thick and are not a perfectly impervious barrier. The coating has a certain degree of porosity and a tendency to behave as a semipermeable membrane. Potentials of the coated tin plate against a reference electrode in carbonated beverage indicate that the coated surface is always cathodic to exposed metal. Reduction processes which might take place through an organic coating will stimulate attack on any areas of exposed steel base.

Organic coated metal in the can acts as a cathodic region; therefore any test method used should evaluate the coating's potentialities as a cathode under conditions which exist in a can. A method was selected to determine the possible corrosion currents such regions could support in an extreme case. To do this, specimens approximately 1½ inches square were cut out of the can body walls and flattened. These areas were selected so as not to include the side seams. Specimens were sealed to flat ground ends of 30 millimeter glass tubing by means of microcrystalline wax. The tubes were filled with air-flushed orange or some other test medium.

Corrosion potentials of cans filled with orange are generally under 0.6 volt negative to a saturated calomel electrode, with the corrosion processes under mixed control. In an extreme case, with a very strong anode present so that the process would be essentially under cathodic control, the potential might be as high as 0.650 volt.

Accordingly, in the test method selected, a saturated calomel reference electrode was put in the test cell and a current imposed by an external source to polarize the exposed organic-coated tin plate to a potential of 0.650 volt negative to the saturated calomel reference electrode. With the very small current required, the saturated calomel reference electrode did not polarize at all; any polarization or resistance effects measured must be considered as taking place at the coated tin plate surface. The current was passed through a resistance of suitable magnitude in series with the test cell. After adjustment of the cell potential to 0.650 volt, a length of time (generally four minutes) was allowed to pass to obtain a relatively stable condition, suitable adjustments being made on the current source as needed. The current necessary to polarize the specimen as a cathode to 0.650 volt was then determined by measuring the potential drop across the resistance in series.

A 12-ounce beverage can has 42.6 square inches of surface area exposed to the product. Since this area is 45 times that used in the tests, the data reported in Table 3 can be multiplied by 45 to secure an idea of the maximum contribution the organic coated tin plate will make to the corrosion processes occurring within the can.

In view of the 0.2 μa postulated as needed to cause perforation or appreciable iron pickup, the organic coatings

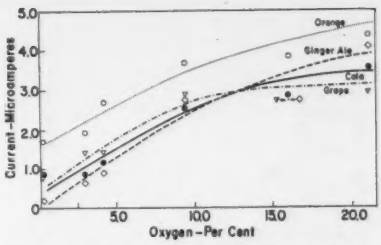

Figure 5—Effect of oxygen in flushing gas on measured galvanic currents with test electrode.

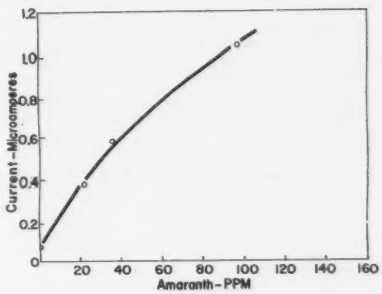

Figure 6—Effect of Amaranth content on measured galvanic currents with test electrode.

on these 20 samples should offer good protection. Any significant corrosion processes occurring in the can must take place at the site of defects in the organic coating.

Table 4 shows results obtained with an organic coating system in use in 1954. Although the data show this system to be a less efficient corrosion barrier than the more recently adopted coating systems, nevertheless this system is adequate. In this connection, it must be remembered that the conditions imposed in this test are rather extreme.

Influence of Steel Base Plate

The corrosivity test electrode previously described was specifically designed to evaluate product corrosiveness and is

TABLE 3—Quality of body-wall for 1955 vintage organic-lined beverage cans

Specimen	Current —10^{-10} Amperes		
	14 Days	21 Days	48 Days
1	1.2	1.2	1.1
2	1.9	0.2	1.5
3	2.2	2.0	2.0
4	2.0	1.3	2.4
5	3.5	5.4	36.0
6	0.0	0.7	....
7	4.3	5.2	....
8	2.0	2.9	3.0
9	3.8	3.7	5.8
10	1.3	2.7	2.1
11	1.3	1.8	1.8
12	1.1	0.6	0.5
13	2.5	1.9	18.0
14	5.3	3.5	4.5
15	1.9	1.1	1.8
16	2.9	2.3	....
17	1.2	0.6	0.4
18	2.0	9.2	9.8
19	1.1	1.4	2.5
20	1.4	1.8	2.5

Current required to polarize 0.95 sq. in. section of body-wall to 0.650 volt negative to saturated calomel in air-flushed orange.

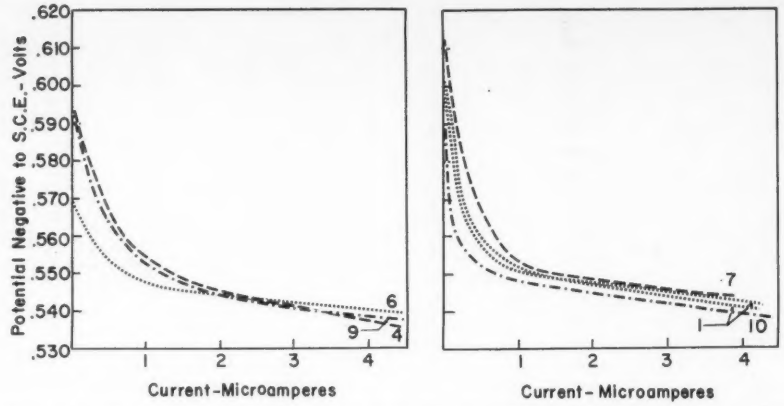

Figure 7—Anodic polarization curves for some MR and L steels in air-free orange drink. Numbers correspond to code in Table 5. Each of the two plots represents specimens simultaneously immersed in same jar of beverage.

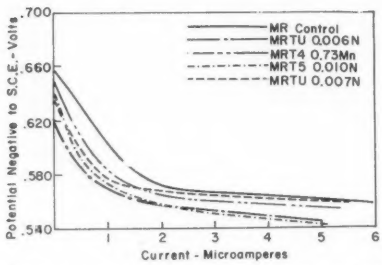

Figure 8—Anodic polarization for steels with limited manganese and nitrogen addition in air-free grape drink.

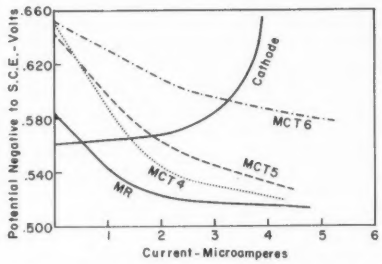

Figure 9—Anodic polarization curve for MC steels in air-flushed grape. A typical cathodic polarization curve for tin in this medium is drawn to illustrate effects on galvanic current.

unsatisfactory for evaluating base plate. In this electrode, the steel anode size is deliberately large so that the process is under cathodic control, cancelling the steel bases's effect. Because corrosion control in a carbonated beverage can generally is mixed, the effect of the base plate varies, depending upon the character of the cathodes existing in the can.

TABLE 4—Quality of body-wall for 1954 vintage organic-lined beverage cans

Specimen	Current—Amperes x 10^{-10}	Specimen	Current—Amperes x 10^{-10}
1	14	11	4
2	80	12	53
3	12	13	173
4	13	14	30
5	13	15	12
6	210	16	14
7	22	17	11
8	13	18	13
9	13	19	8
10	70	20	97

Current required to polarize 0.95 sq. in. section of body-wall to 0.650 volt negative to saturated calomel in air-flushed orange—after 21 days.

Determining anodic polarization curves in various media is the best way of assessing the effect of the base plate.

Anodic polarization curves were determined, using pint-size mason jars of the beverage held at a constant temperature of 77 F. The jars were sealed with rubber stoppers with holes for one or more test electrodes, a calomel reference electrode, a platinum electrode to serve as the auxiliary cathode and for glass tubes through which air or nitrogen flushing gases were passed. Flushing through the product for 2-hour periods was used in these tests.

Eleven samples nominally designated Type MR and Type L steels from six different producers were selected randomly to determine variations existing within these types of steel. Ladle analyses for these heats are given in Table 5. In the tests, the tin plate was first detinned and specimens cut to provide a cross-sectional area of 0.003 sq in. These were mounted in epoxy resin. Anodic polarization curves for these were determined in cola, orange and grape, both air-flushed and air-free.

Three types or grades of base steel are in general use for cans. The main differences among the types are the allowable phosphorus and copper contents. Type L is the most restrictive composition and is specified for the most corrosive foods. Type MR has slightly broader limits for phosphorus and copper; Type MC is a rephosphorized grade used where strength is the major consideration.[4]

Typical results using MR and L type steels, as presented in Figure 7, indicate the anodic polarization curves all lie in the same range allowing interchangeability of these steels for beverage can use. Further work on limited manganese addition and on low nitrogen-bearing steels (Table 6 and Figure 8) also indicate no undesirable effects on corrosion resistance of the plate to the product.

In another series of tests, MCT4, MCT5 and MCT6 steels were evaluated. From the standpoint of withstanding higher internal pressures, MCT6 plate would be desirable. Results for a grape drink are presented in Figure 9. They were variable for the different beverages, but in all cases the MC steels were found to have anodic polarization curves definitely on the anodic side of the MR. In general MC steels, especially MCT6, would be undesirable under the conditions of these tests, the MR and L types appear to offer no problems.

Influence of Tin Thickness and Structural Features

Two types of tin coatings with two enamel systems each were evaluated:

1. No. 25 electrolytic plate (tin coating thickness = 0.000015 inch).
   (a) Modified epoxy base coat with vinyl enamel top coat.
   (b) Modified epoxy base coat with vinyl enamel top coat.
2. 1.25 lb hot dipped plate (tin coating thickness = 0.000065 inch).
   (a) Modified epoxy base coat with vinyl enamel top coat.
   (b) Modified epoxy base coat with vinyl enamel top coat.

The organic coating system comprised two formulations of modified epoxy base coat with the top coat in both cases being the same colorless, vinyl enamel.

Structural features, as indicated in Figure 10, were evaluated in both types of cans because corrosion processes in a beverage can are concentrated at the following structural areas:

1. Soldered side seam.
2. Double seam region, representing the areas in which deformation of metal

TABLE 5—Ladle Analyses of Type MR and Type L Steels

Code	Supplier	Type	C	Mn	P	S	Si	Cu	Ni	Cr	Sn
1	A	MR	.08	.43	.013	.023	.009	.03	....	....	.009
2	B	MR	.14	.48	.012	.041	....	.12	....	....	.020
3	C	MR	.07	.39	.015	.028	.005	.03	.01	.01	....
4	D	MR	.10	.46	.010	.023	....	.09	....	....	....
5	E	MR	.08	.41	.008	.031	.008	.20	....	....	....
6	F	MR	.08	.37	.008	.027	....	.11	....	....	....
7	C	MR	.09	.40	.008	.021	.003	.01	....	....	....
8	B	MR	.11	.42	.010	.031	....	.09	....	....	.016
9	D	MR	.11	.45	.010	.028	.028	.05	....	....	....
10	B	L	.12	.45	.008	.021	....	.055	....	....	.016
11	F	L	.09	.42	.009	.027	....	.06	....	....	....

TABLE 6—Steels Used in Study of Effects of Nitrogen

Code	Supplier	Description
1	C	MRT4 0.73% Mn
2	C	MRT5 0.83% Mn, 0.010% N
3	F	MRTU 0.006% N
4	C	MRTU 0.007% N

takes place with possible damage to enamel coating in the process of double seaming the can body ends.

3. Lap regions at ends of the side seam, consisting of simple lap soldered junctions so that the side seam will not interfere with end seaming.

Corrosion processes occurring at other locations on the body wall and ends need not be specifically considered since the protective power of the organic coating in these areas reduces corrosion to an unimportant level.

These cans were of 1955 structural configuration but did not include the use of cushion seal compound placement in the end unit to minimize double seaming metal exposure.

To determine the way in which the side seam and end seam regions act, 15 cans were selected at random from each of the four groups: five were tested as is, five with the can bottom waxed-off to cover the double seam region and leave the side seam exposed and five were tested with the side seam waxed-off to leave the double seam region exposed.

These cans were filled with air-flushed orange, allowed to stand for three days and corrosion potentials were then determined. In waxing off the cans for the above test, the lap was considered as part of the double seam region because it is a location at which iron may possibly be exposed or a potential locus of anodes. To illustrate this, potentials of the side seam region were determined in a subsequent test with and without the lap exposed in air-flushed cola. These were run for enamel system No. 1 only, for both the 25 lb and the 1.25 lb plate.

As indicated in Table 7, potentials of the side seam area were more cathodic than the can as a whole; potentials of the double seam area were more anodic than the whole can. This shows the side seam region to be the locus of cathodes in a can and the double seam region to be the locus of anodes. Dissolution of metal in the double seam region is stimulated by reduction processes taking place in the side seam region. In carbonated beverage cans, the side seam solder is a considerably stronger cathode than tin; therefore any exposed solder in the side seam contributes to the effectiveness of this region as a cathode.

Results of waxing over or leaving the lap exposed are shown in Table 8. These potentials were taken after the cans were filled with the corrosive medium for one day. In the case of No. 25 plate, potentials with the lap exposed were more anodic than those for the cans with the lap waxed off, indicating a galvanic action in the cans between the cathodic side seam and the anodic exposed lap. The definite difference in potential between the lap and side seam found in the No. 25 plate indicates that in the No. 25 plate cans the lap is a potential source of iron pickup, but its magnitude cannot be predicted. In further test work, the lap, therefore, was considered part of the double seam region rather than the side seam.

A can couple technique was used to measure the galvanic current flowing between the side seam regions and the double seam regions in test cans. Two cans were used as a couple. In one, the side seam exclusive of the lap region was waxed-off, leaving the double seam and lap regions exposed to provide the anode of the can couple; in the other can, the double seam region and lap region were waxed-off, leaving the side seam area exposed to provide the cathode of the couple. The cans then were filled with the corroding medium (air-flushed orange) and couped: externally by means of a wire, internally by means of a bridge filled with the corroding medium. Currents here were so small that the IR drop in the bridge was negligible.

Results of these tests are shown in Table 9. The number of couples tested was not statistically large enough to ascertain differences existing, but the trends are in accord with expectations. The entire test was repeated with about the same results. Excepting that a current of at least 0.2 μa on a single 1 sq mm spot can cause a perforation in a year, data in Table 9 does indicate that some of these cans are in danger of perforating.

In the course of a perforation forming in a can, the steel area exposed at the pit constantly becomes greater. Relatively strong cathodes somewhere in the can are required to enable this to take place. Regardless of the particular beverage under consideration, perforation formation is dependent principally upon cathodic control: the can with the greater cathodic activity tends to perforate faster. Data in Table 9 shows that the 1.25 lb plate in these tests evinced greater

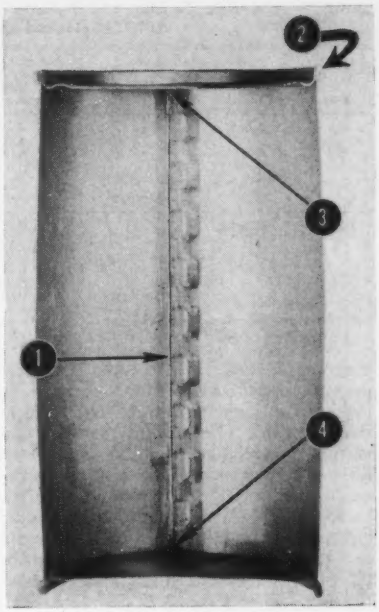

Figure 10—Structural features in beverage can: 1 is side seam, 2 is end double seam and 3 and 4 are lap areas.

cathodic activity than No. 25; therefore, it would be expected to perforate more readily than No. 25 tin plate. Other tests also substantiated that with this organic coating system and the other one tested, the 1.25 lb plate possessed the greater cathodic activity.

No particularly good reason for this can be given other than attributing it to differences in manufacturing practices. It may be a condition which existed only in these cans and would not be duplicated in cans of different manufacture. Effective organic protective coating systems should perform with equal satisfaction, regardless of the plate. Thus from the standpoint of perforations, there is no reason to favor the use of one plate over the other. The point is perhaps somewhat academic because coating systems presently used are so effective that perforations are no longer a major problem.

Iron pickup is a different matter. It takes 0.04 μa to increase the iron content 1 ppm in a year's time. With a limited area of steel exposed, corrosion

TABLE 7—Relationship Between Potentials of Side Seam and Double Seam Regions*

Can Type	Part Tested	Air-Flushed Orange—Three Days: Potential—Volts Negative To S.C.E. 1	2	3	4	5	Average
#25 plate	Whole can	.537	.548	.536	.567	.543	.545
Organic coating	Side seam	.502	.469	.543	.477	.478	.492
System a	Double seam	.549	.586	.517	.576	.563	.558
1.25# plate	Whole can	.550	.516	.510	.497	.496	.514
Organic coating	Side seam	.476	.482	.476	.467	.495	.480
System a	Double seam	.486	.493	.518	.571	.537	.520
#25 plate	Whole can	.573	.540	.564	.541	.535	.545
Organic coating	Side seam	.487	.507	.411	.487	.543	.488
System b	Double seam	.569	.552	.531	.556	.549	.551
1.25 # plate	Whole can	.517	.545	.480	.542	.500	.516
Organic coating	Side seam	.469	.467	.473	.485	.505	.480
System b	Double seam	.543	.545	.531	.553	.524	.540

* Top area is included with double seam region.

TABLE 8—Potentials for Side Seam Regions of Cans of No. 25 and 1.25 lb Plate*

	Can No.	Potential—Volts Negative to S.C.E. No. 25 Plate	1.25 lb. Plate
Lap Waxed Off.	1	.488	.424
	2	.450	.418
	3	.368	.438
	4	.370	.386
	5	.485	.410
	Average	.432	.416
Lap Exposed...	1	.455	.406
	2	.570	.447
	3	.636	.433
	4	.612	.432
	5	.539	.425
	Average	.561	.428

* Air-flushed cola, exposed one day, with and without lap at double seam exposed.

TABLE 9—Galvanic Current and Potential for Cans of No. 25 and 1.25 lb Plate Filled With Air-Flushed Orange, Coupled 4 Days

Body	End	Couple No.	Current Microamperes	Potential—Volts Negative To SCE		
				Side Seam	Couple	Double Seam
No. 25	No. 25	1	0.02	0.520	0.566	0.577
		2	0.02	0.502	0.529	0.536
		3	0.02	0.489	0.522	0.533
		4	0.02	0.482	0.578	0.585
		5	0.01	0.506	0.534	0.536
		Average	0.02	0.500	0.545	0.554
1.25 lb.	1.25 lb.	1	0.01	0.480	0.492	0.501
		2	0.02	0.475	0.496	0.499
		3	0.01	0.495	0.565	0.567
		4	0.00	0.523	0.533	0.533
		5	0.01	0.482	0.488	0.509
		Average	0.01	0.492	0.514	0.522

control is mixed. Therefore, the iron pickup rate must be determined jointly by cathodic activity of the can and area of steel exposed. The current readings tabulated in Table 9 can be interpreted directly in terms of iron pickup by the can contents.

The rate of iron pickup, by virtue of galvanic currents between the side seam and double seam areas, is indicated to be 0.5 ppm or less in a year's time for both the No. 25 and the 1.25 lb plate, with the 1.25 lb plate having a somewhat lower rate of iron pickup than No. 25. However, these galvanic currents do not necessarily represent the total rate of iron pickup in the can: total iron pickup is the equivalent of the galvanic current flowing between the side seam and double seam regions plus any local action which may occur. Such local action is not directly determinable in this test, but reasonable estimates can be used on a comparison of the current and potential results with certain auxiliary data.

In cans representative of 1955 commerical manufacturing practice, local action did not occur significantly in the side seam region although some local action occurred in the double seam region. Thus the No. 25 can might have an estimated iron pickup rate of 1.5 ppm per year whereas the 1.25 lb can's rate would be about 0.75 ppm per year. Because iron pickup rate can be minimized by establishing control over product corrosiveness, use of the new improved organic protective coatings and by cushion seal compound placement, there is no great advantage in using 1.25 lb plate over No. 25 plate except, perhaps, in isolated cases.

Conclusions

The following conclusions are based on the information and data presented:

1. Tin is normally cathodic to exposed steel base in the carbonated beverage can. The corrosion mechanism involved is one of attack on the exposed steel base, stimulated by equivalent reduction processes occurring at exposed tin, exposed solder or enamel covered tin plate—all cathodic to the steel.

2. In modern organic lined carbonated beverage cans, the total current amount which can pass through the coating pores under the potential differences existing is so small that such processes have no influence on the corrosion mechanisms occurring.

3. Corrosion processes in today's commerical carbonated beverage can occur to a significant extent only at locations where there is some discontinuity or imperfection in the organic coating.

4. Corrosiveness of a carbonated beverage is a direct result of reducible materials (depolarizers).

5. Oxygen is a strong depolarizer; therefore it is imperative to minimize the amount of air in the product and in the head space of a carbonated beverage packed in a metal container. Other depolarizers such as those associated with coloring agents also must be kept at a minimum.

6. Corrosivenesss of a beverage is determined by measuring the galvanic current between tin and steel electrodes, using the product as the electrolyte.

7. A minimum galvanic current of 0.2 μa concentrated at a 1 sq mm exposed metal area is required to cause a perforation in a year's time. Best way to prevent perforations is to minimize this current by controlling metal exposure in the can and/or depolarizers in the beverage.

8. No difference was found between Type MR and L steels from various suppliers used in making carbonated beverage cans. Likewise, no effect was found by making limited additions of nitrogen or manganese. Use of MC steels for this application was hazardous.

9. From the standpoint of resisting perforations, 1.25 lb hot-dipped tin plate was not superior to No. 25 electro-tin plate.

Although a slight difference in iron pickup performance was noted, it was not sufficient to warrant use of 1.25 lb over No. 25 plate. Adequate container structures, improved organic coating materials and end seam compounds and control of the corrosiveness of the beverage through reformulation and acceptable packaging procedures give very low rates of iron pickup in cans made from either plate.

References

1. H. T. Johnson, A. W. McAlpin and A. M. Schenck. Some Aspects of Canning Soft Drinks. *Food Technology*, 9, 643 (1955).
2. H. T. Johnson, A. W. McAlpin and A. M. Schenck. Development of Beverage Cans. *Modern Packaging*, 29, No. 4, 150-154 (1955) Dec.
3. H. T. Johnson and J. J. Daly, Jr. Use of Antioxidants in Canned Soft Drinks. *Proc Soc of Soft Drink Technologists*, Page 73 (1957).
4. Making, Shape and Treating of Steel. U. S. Steel Corp., Pittsburgh, pp. 652-653, 1957.

Any discussion of this article not published above will appear in the December, 1959 issue

A Review

Principles and Criteria for Cathodic Protection Of Steel in Sea Water*

By M. H. PETERSON

Abstract

Development of cathodic protection is traced from the initial work of Davy to the formation of an adequate theory of cathodic protection. Techniques used in experimental determination of criteria for protection in laboratory and in field are given with the advantages and limitations of each. Reference list includes 84 items. 5.2.4

Introduction

TO MAKE a reasonable evaluation of the various criteria which have been proposed for use in the protection of steel in sea water by the use of cathodic protection, the historical development of cathodic protection for marine use, first must be considered and the electrochemical nature of the corrosion process reviewed.

Cathodic protection had its beginnings in Davy's[1,2] use of iron sacrificial anodes to protect the copper bottom plating of British war ships and of merchant ships on the long run to India and in his suggestion that zinc could be used for the same purpose as could Voltaic cells if they were of sufficient capacity.

About 1910, Harker and McNamara[3] and Clement and Walker[4] attempted to calculate the protective current required from the weight loss which occurred during free corrosion of specimens. Bengough and May[5] in 1924 and Evans[6] in 1931 postulated that cathodic protection depends upon scale formation or upon the production of some inhibitive substance at the corrosion cell. Evans, Bannister and Britton[7] in 1931 believed that cathodic protection was at least partly dependent upon the redeposition of metal dissolved by the corrosion cell. Bengough, Jones, and Pirret[8] (1920) and Hoar[9,10,11] (1934) recognized that the principal factor in the protection of metal is the prevention of dissolution of anode material.

These useful concepts failed to yield a complete theory of cathodic protection: Davy's[2] research does not tell us how "negative" the copper must be made to prevent corrosion although the idea is suggested that the protected metal must be sufficiently cathodic to prevent the anodic reaction. That the magnitude of the current required to prevent corrosion could be calculated from the weight loss of the freely corroding specimen was widely accepted for many years. As late as 1937, Thompson[12] and Hildebrand[13] were publishing papers giving evidence to disprove this belief.

Evidence in the references cited indicates that cathodic protection is not dependent solely upon the formation of protective films on the protected surface although in some cases, and particularly in the protection of steel in sea water, scale formation or the production of inhibiting substances may materially increase the degree of protection obtained.

The concept that metal must be redeposited is not true in the general case. Edwards and Taylor,[14] Dix,[15] Brown,[16] Brown and Willey,[17] Crennell,[18] and others have demonstrated that cathodic protection can be applied successfully to aluminum alloys and magnesium base alloys. Because magnesium or aluminum probably cannot be reduced from aqueous solution, dissolved metal need not be redeposited to obtain protection.

A more satisfactory explanation of the cathodic protection mechanism was developed independently by Hoar[11] (1937) and Mears and Brown[19] (1938). Although their approach was different, both concluded that the essential condition for complete protection of metal by cathodic protection was that the local cathodes be polarized to the open circuit potential of the local anodes.

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Corrosion Process

Nature of the corrosion cell and of the anodic and cathodic processes are reviewed briefly below as given by Evans[20] and Hoar.[11]

When a metal is immersed in an electrolyte, certain areas of the metal act as anodes; other areas appear to be cathodic. Factors which favor the formation of a cathodic zone are formation of a protective oxide film, presence of dissolved oxygen in the electrolyte close to the metal and a metal-electrolyte interface which catalyses either of the net cathodic reactions:

$$O_2 + 2\,H_2O + 4\,e = 4\,OH^- \quad (1)$$

$$2\,H^+ + 2\,e = H_2 \quad (2)$$

Factors which favor the anodic behavior of a zone are absence of film, absence of dissolved oxygen and an interface having little catalytic effect on the above cathodic reactions. The usual anodic reaction may be written

$$Me = Me^{n+} + n\,e \quad (3)$$

Polarization Curves

The oxygen-electrode reaction[1] should on theoretical grounds give a curve of the form of that shown in Figure 1. Lower portion of the curve is the potential of the reversible oxygen electrode in the electrolyte under study and is a logarithmic curve which is determined by the electron transfer process at the electrode. This portion of the polarization curve for the oxygen electrode has been verified experimentally by Hoar[21] and others. The break in the oxygen dissolution curve comes at the point where the controlling factor in the electrode process becomes the rate at which oxygen can diffuse to the electrode and eventually approaches a limiting value.

Evans, Bannister, and Britton[7] have verified experimentally cathodic polarization curves of this type for several metals. As the potential of the oxygen electrode rises, the hydrogen electrode reaction commences. The polarization curve for the reversible hydrogen electrode (shown in Figure 1) follows a logarithmic form for all current densities. The total cathodic current flowing at various electrode potentials is given by the sum of the currents due to the oxygen dissolution and hydrogen evolution reactions.

Metal dissolution reactions are known to be less easily polarized than gas electrode reactions although some of the transition elements including iron show considerable polarization. Anodic polarization curves take the shape shown in Figure 1, where polarization curves are

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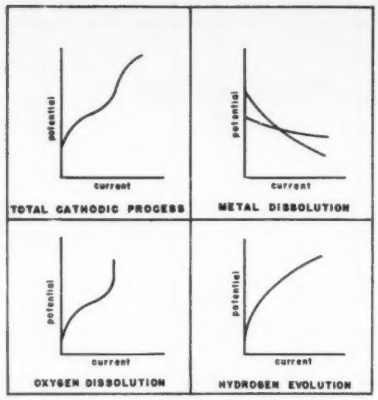

Figure 1—Electrode processes.

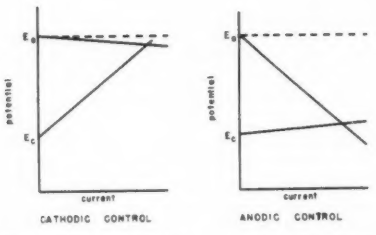

Figure 2—Two electrodes are combined to form a corrosion cell with the anode and cathode polarized to the same potential.

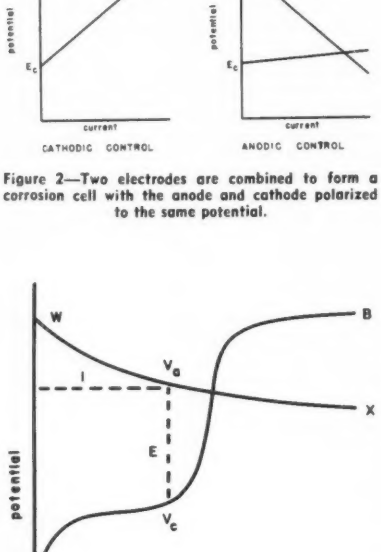

Figure 3—Corrosion cell with anodic and cathodic reactions taking place on the same piece of metal.

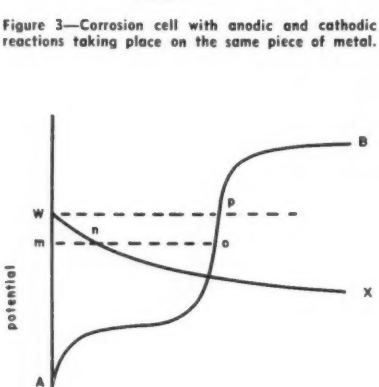

Figure 4—Effect of impressed current.

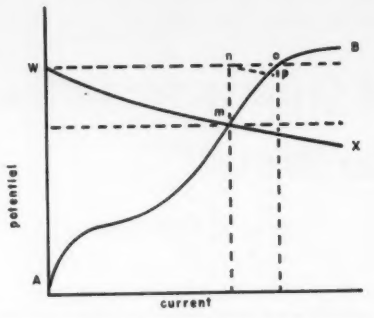

Figure 5—Effect of impressed current on the potentials within the system.

shown for both slightly and appreciably polarized anodes.

When two electrodes are combined to form a corrosion cell as shown in Figure 2, sufficient corrosion current flows so that anode and cathode are polarized to the same potential. The solution potential for the cell depends upon the degree of anodic and cathodic polarization. In this simplified diagram, the polarization curves are assumed to be linear. Shown are the two extreme cases where either the anodic or cathodic process is readily polarized and the other polarized only with difficulty.

The drop in potential due to IR drop in the solution has been neglected because this factor is negligible in the corrosion of steel in sea water. In electrolytes of higher resistivity this IR drop may, however, be of considerable importance and actually may be the controlling factor in determining the corrosion current. Corrosion of steel, copper and most metals in chloride solutions normally is controlled by cathodic polarization.

When the anodic and cathodic reactions are taking place on the same piece of metal, the total current flowing at the two electrodes must be the same. Evans[20] and Hoar[11] have represented the situation as shown in Figure 3. AB is the cathodic and WX the anodic polarization curve. The cathodic and anodic potentials approach each other until they reach values V_a and V_c such that the acting electromotive force is sufficient to drive the current i through the ohmic resistance of the electrolyte. For the case of iron in sea water, resistance of the electrolyte is considered to be negligible so that the anodic and cathodic potentials are equal and the corrosion current is represented by a perpendicular dropped from their point of interception to the current axis.

Modern Theory of Cathodic Protection

Hoar[11] holds that the approach given below to the theory of cathodic protection applies only to cases where the relative areas of the anodic and cathodic zones are not changed by the application of current, and thus in its simplest form would apply best to cases in which no reducible oxide films are present on the surface of the corroding metal. Mears and Brown[10] do not recognize this limitation and believe that the theory adequately explains those cases in which the relative anode-cathode area change with applied current.

If (Figure 4) current is applied to the corrosion cell from an external source, Hoar's approach can be followed and the effect on the corrosion current considered. With no applied current, the corrosion is given by the intercept of the point of intersection of the polarization curves upon the current axis and is equal to the anodic current which in this case is also equal to the cathodic current. As cathodic current is applied the anodic and cathodic currents are no longer equal but differ by the amount of the applied current so that "mo" represents the total current, "no" the applied cathodic current and "mn" the anodic or corrosion current. Application of cathodic current equal to the original corrosion current will not reduce the anodic current to zero, and the anodic current will not be reduced to zero until sufficient external current is applied to polarize the cathode to the open circuit potential of the anode as represented by point p.

The theory of cathodic protection also can be approached as Mears and Brown did by considering the effect of impressed current on the potentials within the system. In Figure 5, the current which causes corrosion, again neglecting the small IR drop thru the metal and solution, is represented by the intersection of the two curves, point "m." Because of the polarization caused by the current flow from the anode areas through the solution to the cathode areas, the potential of all points on the surface of the metal is equal. This nearly equipotential surface is obtained by a current flowing from the local anodes and is accompanied by anodic dissolution or corrosion.

If the current required to produce this equipotential surface can be furnished from some source other than the local anodes, the local cathodes can be polarized to the intersection "m" independently of any current from the local anodes. Under these conditions, however, the local anodes, because of the reduction in anodic current, would no longer be polarized to "m" but would be anodic to point "m" and corrosion current would still flow. If the cathodes are now polarized further by an external current until the cathode areas reach a potential equal to the open circuit potential of the anodes (Point "o"), the entire surface is equipotential without the local anodes furnishing any current. Thus no current will flow in the cell if corrosion is entirely electrochemical. Complete protection will be obtained if no corrosion results from products of electrolysis formed around the cathode.

The theories of cathodic protection advanced independently by Hoar and by Mears and Brown are equivalent, but a consideration of the corrosion process and cathodic protection from both standpoints gives a better understanding of the process. The theory's essential element is that local cathodes must be

polarized to the open circuit potential of the anodes.

Determination of Criteria for Cathodic Protection

The amount of applied cathodic current bears no simple relationship to the degree of protection obtained in practice. There are several approaches to the problem. Theoretically, the open circuit potential of the anodic areas on a piece of corroding steel can be calculated and the steel polarized to this potential. The empirical current density required for protection can be determined or the degree of polarization required by laboratory and field experiment. The possibility of a break in the potential applied current curve at the protective potential also can be investigated. Brief review of the techniques used in these investigations and some of the results reported are given below.

Theoretical Calculation

In Figure 6 a typical method of calculating the open circuit potential of the anodic areas of corroding steel is given. Corrosion of iron in water follows a reaction of the form of Equation 1, at least in neutral water at approximately room temperature.

The anode reaction is given by Equation 2, and the potential of the half cell is dependent only on the concentration of ferrous ions in the solution. If the supply of oxygen is limited, concentration of these ions probably is controlled by the solubility of the ferrous hydroxide formed. Using the latest value available for the solubility product of ferrous hydroxide as reported by Leussing and Kolthoff[22] the concentration of ferrous ions which would be present in a saturated solution of ferrous hydroxide such as might exist on the surface of an active anode can be calculated. (Equation 4).

This value in turn may be substituted in the Nernst equation with the known standard potential for the iron anode. As shown, this yields a value of —0.59 volts relative to the hydrogen electrode or —0.83 volts relative to the saturated calomel electrode. This is approximately 0.88 to the saturated copper/copper sulfate electrode often used in corrosion work. Such a simple approach will yield only an approximate value in any practical situation. The Nernst equation is relatively insensitive to the value of ferrous ion concentration. The calculations as given will hold only for pure water in which the pH is the equilibrium pH for ferrous hydroxide (about 9.3). Corrections necessary to find an open circuit potential for sea water can be estimated. Because the correction is small and the method at best gives only an approximation of the true open circuit potential, further correction is not worthwhile for purposes of this review.

Laboratory Determination

Some of the laboratory techniques used to develop criteria for cathodic protection are given below. First, there are the direct methods, the most obvious of which is to expose replicate weighed specimens of a metal to sea water and to supply different cathodic current densities to several specimens. After a definite length of time the specimens are cleaned and reweighed. The weight loss or "percent protection" is then plotted as ordinate against the protective current density. This procedure is simple in outline. Direct methods form the standards against which all other methods are tested, but unfortunately this simple procedure is not easy to carry out in practice.

Various cell designs have been used by Hill,[23] Thompson,[24] Wesley,[25] Brown and Mears[26] and others in attempts to assure that the current distribution of the cathodic current is substantially uniform over the cathode surface.

These efforts have not been completely successful; variability of data among replicate samples makes interpretation difficult. Also the exposure time must be extended over long periods if measurable weight changes are to be obtained, and the weight loss in cleaning may be the same or greater than the corrosion loss in the protective current range. Unfortunately the percent of experimental error is at a maximum where the greatest precision is desired.

Several investigators have used indirect analytical methods to study the minimum protective current density. Evans, Bannister, and Britton[7] used ferricyanide indicator. When the cathodic current was insufficient to prevent the dissolution of iron, a blue color was formed in the vicinity of the iron surface. Kehn and Wilhem[27] removed their samples from the corroding medium, added the corrosion products to the medium and determined the ferric ion concentration in the acidified mixture colorimetrically using thiocyanate indicator.

Other investigators attempted to establish other criteria for protection from the shape of the mean potential curve of freely corroding surface when cathodic current is supplied from an external source. Evans, Bannister, and Britton,[7] Pearson,[28] Ewing,[29] Holler[30] and others plotted the solution potential of the specimen against the applied cathodic current and found a sharp break at what they believed was the minimum protective current. This situation is represented in Figure 7, taken from work by Mears and Bialosky.[31] The corrosion cells have been drawn to show the IR drop through the solution as negligible.

Examination of Figure 7 shows that, when current from an external source is applied to a freely corroding specimen, the shape of the resulting current-potential curve is dependent upon the relationship of the overall potential of the specimen at zero applied current to the open circuit potentials of the local anodes and cathodes. Where there is little or no anodic polarization, as is generally the case in the corrosion of steel in sea water, a sharp break occurs in the potential-applied current curve at

(1) $Fe(s) + 2H_2O(l) \rightarrow Fe(OH)_2(s) + H_2(g)$ Cell Reaction

(2) $Fe(s) \rightarrow Fe^{++} + 2e$ Anode Reaction

(3) K_{sp} of $Fe(OH)_2 = 8 \times 10^{-16}$ Leussing & Kolthoff (1953)

(4) $C_{Fe^{++}} \times C^2_{OH^-} = 8 \times 10^{-16}$

$C_{Fe^{++}} \times (2C_{Fe^{++}})^2 = 8 \times 10^{-16}$

$C_{Fe^{++}} = 5.9 \times 10^{-6}$ gm. ion / liter

(5) $E = E_o + \frac{0.058}{N} \log_{10} C_{Fe^{++}} = -0.59$ volt

(6) $E = -0.59 - 0.24 = -0.83$ volt to saturated calomel

Figure 6—Calculation of the theoretical protective potential.

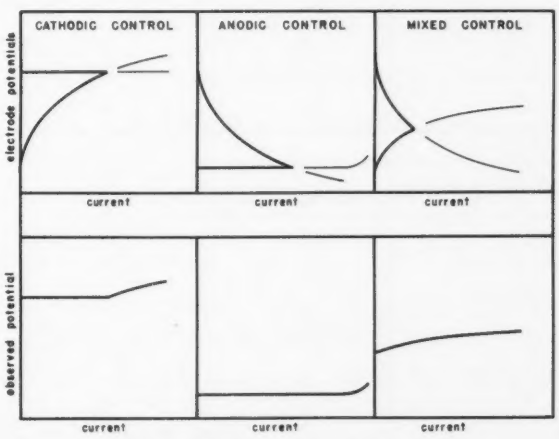

Figure 7—Potential break as a criterion for protection.

the point where the local anodes first start to polarize cathodically. That is, in this case, the open circuit potential of the anodes. For corrosion cells with mixed control or for cells with cathodic control, this is not true.

In the case of mixed control, there may or may not be a break in the potential curve depending upon the shapes of the anodic and cathodic polarization curves. Generally this break, if it occurs, will not come at the open circuit potential of the anodes. In the extreme case where there is little or no polarization of the cathodes, the break in the potential curve indicates only that sufficient cathodic current has been supplied to start polarizing the local cathodes.

The potential break method is applicable only to those cases where the polarization of the local cathodes is much more evident than the polarization of the local anodes. The curves in Figure 7 are idealized curves based upon the assumption that the open circuit potentials of the local anodes and cathodes are not altered by the products of electrolysis and that the anode and cathode areas remain constant. Therefore, the potential break in any practical case may be much less distinct than indicated. More recent work by Logan[32] and Howell[33] has questioned the advisability of using potential break methods as criteria of protection under any conditions.

Criteria For Use in Cathodic Protection

The most generally accepted criterion for the protection of steel in sea water is the polarization of the steel to —0.85 volt relative to a saturated $Cu/CuSo_4$ electrode. But as recently as 1949, a questionnaire sent to NACE members by Smith[34] yielded such a diversity of answers that no criterion for cathodic protection was available from the replies. Because of the contradictory reports of the current densities and potentials required to cathodically protect steel, this material is summarized in Tables 1 and 2.

Table 1 shows many of the criteria for protection which have been reported from laboratory investigation. Values reported for the potential required for protection are in fair agreement, but the current densities reported are too diverse to be useful for design purposes.

Table 2 summarizes some of the criteria developed by field application of cathodic protection. Here again, there is better agreement as to the protective potential required than as to the current density which will give this potential.

The values given for NRL have been developed from data obtained in the cathodic protection of over 30 active and reserve vessels for periods of three years and up.[68-80] The potentials measured in this work represent, in general, a composite of potentials of various areas of the hull and its appendages.

In most cases a current density of three milliamperes per square foot is more than sufficient to polarize a hull with paint substantially intact. No evidence was found to show that a different potential is required for protection in fresh water than in salt water if care is taken to avoid the inclusion of IR drop in the potential measurement. Evidence did indicate that a higher protective potential is required in some badly polluted waters.

The three principal criteria now in use may be summarized as follows:

1. Polarize steel to —0.85 relative to saturated $Cu/CuSo_4$.

2. Apply current density of 3 to 10 ma/sq. ft.

3. Change the potential of the steel 0.3 volt relative to a remote anode.

Under certain conditions such as in polluted waters, these criteria may not apply. Patterson[81, 82] and Mortensen[83] have published a series of papers which suggest that potentials more negative than 0.85 volt will be required when anaerobic bacteria are present. Wheatland and Laird[84] have found that phosphor-bronze electrodes are more cathodic than mild steel when immersed in normal sea water but become more anodic than steel when sulfide ions are present. This suggests that excessive corrosion of propellers and shafts in polluted waters may be due to this reversal and that this possible reversal of potential should be considered in the application of cathodic protection. The work of LeFebvre and Sudrabin[84] on the composition of material found in rust tubercles suggests that the pH of the material found in these tubercles is independent of the pH of the surrounding medium but that the pH rises when adequate protective current is applied and the pits are no longer active.

TABLE 1—Criteria for Protection Reported From Laboratory Work

Investigator (Given By Reference Numbers)	Current (ma/sq. ft.)	Volts To Cu/Cu SO_4	Remarks
35	10	.....	Sea water
36	93	.....	
37	48	.....	In Na Cl
38	....	—0.88	
23	10	$\triangle E = 0.3$	Sea water
27	12	.....	5% Na Cl
39	....	$\triangle E = 0.3$	
40	3	.....	
41	15	.....	Synthetic sea water
42	19	.....	Sea water
43	7	.....	Sea water
44	....	—0.86	Sea water
45	325	.....	Sea water
23	12	.....	Synthetic sea water
46	32—74	.....	3½% sea salt
47	15	.....	Sea water
48	15	.....	Sea water
3	3	.....	Sea water
49	230	.....	Neutral solutions
50	165	.....	3½% Na Cl
51	6	.....	Sea water
52	6	.....	Sea water

TABLE 2—Criteria for Protection Developed by Field Application of Cathodic Protection

Investigator (Given By Reference Numbers)	Current (ma/sq. ft.)	Volts To Cu/Cu SO_4	Remarks
53	2	—0.80	For tank bottoms
54	15	.....	For tank bottoms
55	16	$\triangle E = 0.3$	For tank bottoms
56	3	—0.85	For tank bottoms
57	....	—0.85	
58	20	.....	Sea water
59	3—10	.....	Sea water
60	2	.....	Sea water
61	....	—0.86	Ship installation
62, 63, 64, 65, 66	2	—0.79	Ship installation
67	....	—0.85	Ship installation
33	10	.....	Pipe line
67	15	.....	Outfall sewer
68-80	....	—0.85-0.95	Reserve fleet

References

1. H. Davy. *Phil Trans Roy Soc*, **114**, 151, 242 (1824).
2. H. Davy. *Phil Trans Roy Soc*, **115**, 328 (1825).
3. G. Harker and J. McNamara. *J Soc Chem Ind*, **29**, 1286 (1910).
4. J. K. Clement and L. V. Walker. *Trans Electrochem Soc*, **22**, 193 (1912).
5. G. D. Bengough and R. May. *J Inst Metals*, **32**, 245 (1924).
6. U. R. Evans. *Metals and Alloys*, **2**, 62 (1931).
7. U. R. Evans, L. C. Bannister and S. C. Britton. *Proc Roy Soc*, **131A**, 355 (1931).
8. G. D. Bengough, R. M. Jones and R. Pirret. *J Inst Metals*, **23**, 127 (1920).
9. T. P. Hoar. *Trans Faraday Soc*, **30**, 480 (1934).
10. T. P. Hoar. *J Electrodepositors Tech Soc*, **14**, 33 (1937).
11. T. P. Hoar. *Trans Electrochem Soc*, **74**, 529 (1938).
12. M. DeKay Thompson. *Trans Electrochem Soc*, **69**, 155 (1936).
13. A. Hildebrand. *Mitt Kohle-u Eisenforsch GMbH*, **1**, 199 (1937).
14. J. D. Edwards and C. S. Taylor. *Trans Electrochem Soc*, **56**, 27 (1929).
15. E. H. Dix, Jr. *Mining and Met*, **8**, 395 (1927).
16. R. H. Brown. U. S. Patents 1,997,165; 1,997,166 (1935).
17. R. H. Brown and L. A. Willey. U. S. Patent 2,011,613 (1935).
18. J. T. Crennell. *Chemistry & Industry*, 204 (1954).
19. R. B. Mears and R. H. Brown. *Trans Electrochem Soc*, **74**, 519 (1938).
20. U. R. Evans. Metallic Corrosion, Passivity and Protection. Arnold (1937).
21. T. P. Hoar. *Proc Roy Soc*, **142A**, 628 (1933).
22. D. L. Leussing and I. M. Kolthoff. *J Am Chem Soc*, **75**, 2476 (1953).
23. W. R. Hill. *Petr Eng*, **12**, 51 (1941).
24. M. deKay Thompson. *Trans Electrochem Soc*, **73**, 550 (1938).

25. W. A. Wesley. *Trans Electrochem Soc*, 73, 546 (1938).
26. R. H. Brown and R. B. Mears. *Trans Electrochem Soc*, 81, 455 (1942).
27. G. R. Kehn and E. J. Wilhelm. *Corrosion*, 7, 156t (1951).
28. J. M. Pearson. *Trans Electrochem Soc*, 81, 485 (1942).
29. S. Ewing. *AGA Proceedings*, 22, 613 (1940).
30. H. D. Holler. *J Electrochem Soc*, 97, 271, 453 (1950).
31. R. B. Mears and J. M. Bialosky. Cathodic Protection—A Symposium, p. 37, (National Association of Corrosion Engineers and the Electrochemical Society) (1949).
32. K. H. Logan. *Corrosion*, 10, 206t (1954).
33. R. P. Howell. *Corrosion*, 8, 300t (1952).
34. A. V. Smith. *Corrosion*, 5, xi (1949).
35. Bauer and O. Vogel. *Mitt Kgl Materialprufungsamt*, 36, 114 (1918).
36. W. van Wullen-Scholten. *Metalbourse*, 19, 1240, 1295, 1517 (1929).
37. M. deKay Thompson. *Trans Electrochem Soc*, 69, 155 (1936).
38. D. Harrell and M. Clerc. *Petr Engr*, 11, 38, 64 (1939).
39. S. Thayer. *Proc API*, 14, Sect. IV, 143 (1933).
40. G. I. Rhodes. *Proc AGA Nat Gas*, 240 (1935).
41. G. S. Gordon. NRL Report P-2389 (1944).
42. J. T. Crennell. Adm. Corr. Committee Report ACC (1944).
43. F. Wormwell. Chemical Research Laboratory (Teddington) Memo N/44.
44. INCO, International Nickel Company. Summary of Discussions at Informal Conference on Cathodic Protection of Steel in Sea Water, (1946).
45. T. P. Hoar. Adm. Corr. Committee Report ACC 3/43 (1943).
46. NRL Letter Report S19-5 (456); 456-24/45.
47. H. H. Uhlig. *Corrosion*, 3, 173t (1947).
48. H. J. Keeling. *Gas*, 15, 31 (1939).
49. D. S. McKinney. *Trans Electrochem Soc*, 75, 31 (1939).
50. W. A. Wesley. *Trans Electrochem Soc*, 73, 539 (1938).
51. C. H. McRaven. Panama Canal Special Engineering Division Report (1942).
52. R. A. Humble. *Corrosion*, 4, 358t (1948).
53. D. H. Bond. *Petr Eng*, 11, 100 (1940).
54. S. Ewing. *Proc AGA*, 22, 613 (1940).
55. W. F. Rogers. *Petr Eng*, 12, 156 (1940).
56. R. A. Brannon. *Petr Eng*, 13, 92 (1942).
57. M. C. Miller. *Petr Eng*, 15, 57, 101, 103, 208 (1944).
58. L. P. Sudrabin. *Corrosion*, 2, 175t (1946).
59. H. A. Humble. *Corrosion*, 5, 292t (1949).
60. M. E. Parker. *World Oil*, 131, 253 (1950).
61. J. P. Oliver. *Trans AIEE*, 71 (pt 2), 324 (1952).
62. K. N. Barnard. *Can J Research*, 26F, 374 (1948).
63. K. N. Barnard. *Can J Research*, 28F, 417 (1950).
64. K. N. Barnard. *Corrosion*, 7, 114t (1951).
65. K. N. Barnard. *Chemistry & Industry*, 204 (1954).
66. K. N. Barnard and G. L. Christie. *Corrosion*, 6, 232 (1950).
67. A. L. Abbott. *S African Ind Chemist*, 7, 233 (1953).
68. L. J. Waldron and R. L. Benedict. NRL Report 4210 (1953).
69. E. E. Nelson and L. J. Waldron. NRL Memorandum Report 232 (1953).
70. L. J. Waldron and R. L. Benedict. NRL Memorandum Report 255 (1954).
71. L. J. Waldron and E. E. Nelson. NRL Memorandum Report 291 (1954).
72. L. J. Waldron and R. L. Benedict. NRL Memorandum Report 292 (1954).
73. L. J. Waldron and R. L. Benedict NRL Memorandum Report 336 (1954).
74. L. J. Waldron and R. L. Benedict. NRL Report 4317 (1954).
75. E. E Nelson. NRL Report 4525 (1955)
76. L. J. Waldron. NRL Report 4587 (1955).
77. L. J. Waldron and M. H. Peterson. NRL Report 4635 (1955).
78. L. J. Waldron and M. H. Peterson. NRL Report 4636 (1955).
79. L. J. Waldron and M. H. Peterson. NRL Report 4637 (1955).
80. L. J. Waldron and M. H. Peterson. NRL Memorandum Report 437 (1955).
81. W. S. Patterson. *Trans N E Coast Inst Engrs & Shipbuilders*, 68, 93 (1951).
82. W. S. Patterson. *J Brit Shipbuilding Res Assoc*, 7, 67 (1952).
83. A. Mortensen. *Ingeniqren*, 63, 306 (1954).
84. F. J. LeFebvre and L. P. Sudrabin. *J New Engl Water Works Assoc*, 64, 309 (1950).

DISCUSSION

Discussion by Mills Dean, III, Navy Department, Washington, D. C.:

(1) You have shown very clearly that through the use of electric supply currents corrosion cell activity can be controlled. On the basis of your experience, would you say that if a ship hull coating were devised that would maintain the electrical insulation indefinitely throughout the underwater parts of the vessel that the corrosion problem would be eliminated?

(2) Would it follow therefore, speaking in general terms, that the prevention of corrosion could be referred to as an electrical insulation problem rather than one of cathodic protection?

Reply by M. H. Peterson:

(1) If it were possible to maintain a perfectly insulating coating on the hull, corrosion would certainly be prevented. However, there would seem to be little chance of developing such a coating because of the mechanical damage often suffered on the underwater portions of the hull. Even if there were no failure of the paint film, there would still be bare areas caused by the abrasion of the anchor chain and other mechanical factors.

(2) Except in unusual circumstances, I would not advocate the replacement of the paint system of a marine hull by cathodic protection, but rather that the best available paint system be augmented by cathodic protection. In the absence of cathodic protection, the danger of pitting may actually be increased by the use of paints of higher electrical resistance as the corrosion which would normally be spread over a rather large area may be concentrated at a few breaks in the paint film. Our problem is not to decide between cathodic protection and paint films but rather how to stop the current flow in the corrosion cell. I think that this can most economically be done by combining all of the methods at our disposal rather than concentrating on one alone.

Any discussion of this article not published above will appear in the December, 1959 issue

TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Planning a Maintenance Coating Program For a Pulp and Paper Plant*

By M. W. Belue, Jr.

Introduction

CONSIDERABLE PROGRESS has been made in the development of new materials, equipment and application techniques. These developments, if carefully evaluated and properly used, can contribute to the success of any paint program.

Although most industrial plants attempt to keep pace with new developments in production processes, few plants have a carefully engineered, effective paint program which uses the latest painting developments.

This article reviews briefly the action taken by a paper and fiber company to alleviate some corrosion problems through careful planning and use of modern material and equipment.

This article does not explain how to plan all maintenance painting programs. Each plant has individual problems and conditions which require separate attention or consideration. However, criticisms and information presented may stimulate interest in better painting programs.

Blocking Forces

Many plants fail to achieve a well organized and successful paint program because of powerful blocking forces which are difficult to overcome. These forces are powered by the action or inaction of management, material suppliers, contractors or labor.

Management

Often a weak or too busy management, willing to follow the line of least resistance, continues to use antiquated materials and painting procedures which through custom have been used for several years.

Stringent economic regulations or conditions sometime result in the use of improper materials and acceptance of substandard specifications.

Modern painting, as described in this article, requires experienced, competent personnel with the ability to plan and execute a workable program. Unfortunately, few plants have men with all the necessary qualifications.

Management usually considers painting a necessary evil and takes little action to increase the respect and pride of the painter or those concerned with painting program.

Suppliers

Suppliers have lagged far behind in providing trained, experienced salesmen and technical men to service their products. Suppliers often oversell or misrepresent their materials. This is rarely deliberate but caused by eager salesmen with inadequate experience and technical knowledge.

Literature and technical sheets usually have insufficient data required or needed by the user. New materials frequently are placed on the market with little or no field testing which should be the final criterion. Many paint failures have been traced to inferior material caused by lack of quality control on the part of the supplier.

One or a combination of the above factors has created mistrust and lack of proper cooperation between the supplier and user.

Contractors

Many experienced people believe that the use of contractors is the most desirable solution to the labor problem. Nevertheless, choice of contractors should be made with care. All work should have clear and strict specifications enforced by competent inspection.

The following five points are points on which contractors have been criticized:

1. Contractors sometimes will furnish labor inexperienced in the class or quality of work desired.

2. Will underbid on work and then cut corners to keep from losing money.

3. The average contractor on a contract price job is usually more interested in production than quality.

4. Supervision even at its best is none too good. Many supervisors have little training or experience in application of special materials.

5. Lack of finances can lead to use of improper tools and equipment.

Labor

Space will not permit an explanation of why the painting profession ranks at the bottom of the ladder, but the criticisms and social treatment normally afforded the painters leave little room for incentive or job pride.

In the final analysis, the success of any paint program depends on labor. If materials are not properly applied, maximum service life will not be attained.

In most areas where union labor is mandatory, no formal training, test or experience is required for classification as a skilled painter. The only prerequisite is the necessary entrance fee and monthly dues.

Too often the painting labor available in plants is not qualified through experience or training to produce the quality work necessary for maximum service life of paints.

★ Submitted for publication March 19, 1959. A paper presented at a meeting of the 15th Annual Conference, National Association of Corrosion Engineers, March 16-20, 1959. Chicago, Ill., and at a meeting of Southeast Region NACE, Jacksonville, Fla., October 1-2, 1959.

About the Author

M. W. BELUE, JR., is protective coating consultant at the Texas division of Champion Paper & Fiber Co., Pasadena, Texas. A graduate of Duke University, he formerly was president of a firm which he organized handling sales and special application of corrosion preventive materials.

Abstract

Reviews action taken by a Texas paper and fiber company to alleviate corrosion problems by a carefully planned coatings program. Factors which stimulated the interest and action of management are given. Phases of a program submitted to management for approval are discussed. Includes objectives of program, selection of materials, surface preparation, application, inspection, records and estimated cost of program. Other items such as estimating and special coatings and linings are given briefly. 5.11

The persons involved in many cases are aware of these conditions and are making every effort to rectify or improve these problems. For example, the Coating Society of the Houston Area, composed of over 200 members, was formed in 1955 with the following objectives:

To further the knowledge of surface preparation and application of coatings for all concerned by practical round-table discussion. The non-technical phase is emphasized.

Interchange of ideas, experiences, policies, etc., among members.

Better understanding by users, suppliers and contractors of their mutual problems.

Reason for Establishing Program

In early 1955, the paper and fiber company used as a study for this article realized that the painting over a period of 12 or more years had given unsatisfactory protection. Cost of corrosion had been extremely high not only in repair and replacement of metal but in damage to products by contamination, loss of efficiency, creation of safety hazards and in psychological factors created by a drab and colorless plant.

Immediate action was taken to establish a new position designated as Pro-

tective Coating Consultant. This position was filled by a person with long and diversified experience in the paint field. His primary responsibility was to plan and execute a practical paint program.

Evaluation of Existing Program

Logically the first step was to study all the facts concerning the existing program. It was of vital importance to know how and what had been accomplished in the past years. This involved consideration of the following items:

Type of materials used, service life attained, specifications, type of equipment available, abilities of painting supervision and labor, job records, inspection procedures, job costs, exposures, atmospheric conditions and condition of present painted surfaces.

In a paint program, these items should be given careful thought. These are the factors which influence or control painting quality, production and service life of the coating.

Suggested Paint Program

The evaluation required several months, and the results indicated that a program using modern materials and equipment would be required to achieve the objectives desired by management.

The program needed involved a change in painting operations and expenditure of considerable money over a period of years. Therefore, it was necessary to submit a comprehensive report to management outlining a suggested program with supporting data.

Objectives

Objectives of the suggested program were given under three points:

1. Preservation of Metal: Once a surface starts rusting, accelerated localized attack or pitting occurs, especially when subjected to high humidities and chemical fumes. If this is not prevented or controlled, serious damage or loss of structure member involved will result.

Survey of the plant indicated moderate to extreme corrosive conditions caused by chlorine gas, salt cake, brine, caustic, chlorine dioxide, hydrogen sulphide and other reagents. These conditions combined with an average humidity of about 70 percent presented a difficult problem.

The objective was to achieve maximum protection of steel surfaces for six years or longer at the least possible cost.

2. Decorative: Color used with imagination and in proper proportions will increase a man's pride in his job and his company. Decorative use of color costs little more than painting according to whim, but the dividends are many. An attractive industrial plant definitely is a community relations asset.

Color schemes should be selected which are pleasing to the eye and practical with respect to application, color retention and weathering.

3. Functional: In addition to preserving steel and beautifying the plant, safety can be promoted. Predetermined color schemes can be used to mark ladders, danger areas, define machinery, railing, fire equipment and any other special or specific areas.

Selection of Materials

Selection of materials as given in the suggested program contained two points:

1. Materials: The most important step in coating is surface preparation. The cost may run from 35 to 75 percent of the total painting cost. Careful selection of materials that deteriorate slowly, have excellent chemical resistance and can be easily maintained, can help eliminate preparation cost as a non-recurring item and thus reduce the cost per square foot per year.

The exclusive use of vinyl and epoxy systems, with minor exceptions, are recommended for the above and following reasons:

a. Excellent chemical resistance and long life.

b. Fast drying, minimum recoating time and less opportunity for contamination between coats.

c. Simplifies purchasing. Better prices obtained because of larger quantities.

d. Simplifies storage. Not necessary to store numerous types, colors, thinners and cleaners.

e. Use of good materials and colors will increase job pride and result in better quality work.

f. Use of only two types of materials allows supervision and labor to become more proficient in its application. Will result in better quality work at a lower cost per foot.

g. Simplifies specification writing and inspection.

h. Fast drying decreases amount of overspray and fog, therefore minimum cover-up needed.

i. Decreases paint losses because of left-overs.

2. Suppliers: Over a period of years there has been noted a significant difference in formulation, solids content, adhesion and chemical resistance of similar generic types.

Choice of suppliers will be based on over ten years' experience in use of materials or observation of their successful use by other plants under similar conditions.

Surface Preparation

Surface preparation in the suggested program was emphasized because the success of any paint system is dependent upon the method and quality of cleaning. Mill scale, rust, dirt, oil or other foreign matter must be removed to attain maximum coating service. Cleaning before 1955 had been accomplished by wire brushes and hand scrapers. These methods were not only slow but inadequate to provide the clean surface necessary for the types of materials suggested above.

Sandblasting on all surfaces where conditions permit is recommended. Specification will normally call for blasting to white metal. This method is accepted as the ultimate in surface preparation. It does an excellent cleaning job and provides a good anchor pattern. This increases the adhesion and extends coating life.

Where production processes or other factors prohibit sandblasting, small, light, disc sanders can be used. A good cleaning job can be accomplished with this tool if properly used.

There will be special conditions under which it will be necessary to use other methods such as

Pickling, chemical cleaning, flame priming, flame blasting and steam cleaning.

Application

The best materials that money can buy are of little value if used or applied improperly. Application procedures should be governed by the manufacturer's application instructions and specifications outlined in the Steel Structures Painting Manual.

Generally, three and four coat systems will be specified with a minimum thickness of 5 mils depending upon the location and exposure involved. After sandblasting, all coats including primers will be applied by spray gun. On disc-sanded surfaces, the prime coat will be brushed and subsequent coats sprayed. Each coat will be of a different color or shade to eliminate holidays and facilitate inspection.

Inspection

The success of the program depends on an inspection system to insure strict adherance to specifications. The inspection will fall into two categories: daily and annual.

Daily Inspection: The contractor foreman will inspect carefully all surfaces prior to applying each coat of material and after completion of each job under his supervision.

Company inspector will closely observe foremen and painters to insure correct use of materials and equipment. He will make periodic inspections during the day to see that specifications are being followed. Film thickness gauges both wet and dry will be used to check film thickness.

Annual Inspection: A preventive maintenance program will be established. A part of this program will be inspection at yearly intervals of each completed major job. An inspection report will be written and work orders initiated for necessary repairs.

Records

Records are an essential part of any operation. Forms will be designed to accumulate and communicate pertinent painting data as follows:

1. Estimating Work Sheet: A work sheet used to accumulate square footage of jobs for estimating purposes.

2. Painting Estimate and Specifications: job estimates and specifications will be recorded on this form.

3. Painting Cost Record: Transmitted to contractor as a work order and specification sheet. Contractor will post daily hours worked and materials used on this form. On completion of job will be returned to consultant's office as a permanent job record.

4. Work Completed Report: Information from cost painting record used to make this report which will be submitted monthly to management showing jobs completed and other necessary painting data as follows:

Job description and work order number; brief specifications; square footage; scaffolding, cleaning and painting labor costs and material costs with manhours and cost per foot for each item; and estimated and actual total job costs.

5. Preventive Maintenance Inspection Report.

6. Essential Data Sheet: All suppliers of material will be required to fill out and submit this form before any materials will be tested or used.

Other Recommendations

In order to accomplish the program outlined, consideration of the following recommendations is requested:

1. Selection of a new responsible contractor who will furnish competent supervision and labor.

2. Contractor to furnish all labor and equipment on a cost of labor plus a fixed percentage markup basis.

3. Increase plant painting force to 30 men. 27 cleaners and painters plus 3 foremen.

4. Contractor to furnish latest sandblast and painting equipment available. Type of equipment will be specified by the paper company.

5. Contractor to establish a training program to indoctrinate the crew in proper use of materials and equipment. Protective Coating Consultant to make suggestions and provide any needed technical aid in this training program.

Cost of Program

The original plans submitted to management outlined structural steel, pipe racks, tanks and piping which a survey indicated should be painted within a 3-year period. This did not include all paintable surfaces in the plant, and the cost was based on confining the crew in large areas to increase production efficiency.

Modification and expansion of this program was necessary to include new construction, miscellaneous work, major work not included in original program, glazing, preventive maintenance and tank linings. This modified program included all surfaces to be painted in major structures plus the additional work listed above.

The above figures were used as a base to project and submit to management the estimated cost, number of men and time to complete the initial paint cycle.

Safety

Last but not least in importance will be safety in the painting program. Contractor will be required to adhere to written company rules plus other rules which are recognized as safe standard painting practice.

Estimating

Good estimating requires experience either through past records of a plant or a person familiar with painting operations. Even then, an accurate estimate is difficult because factors as those listed below can vary from job to job: Scaffolding and accessibility, condition of surface, weather conditions, supervision and labor, equipment, specifications, wage rates, overhead or mark-up and possible interference with production processes which result in slowing or stopping of painting work.

A simple method of estimating is shown by the following example of a painting job on a new recovery building. Structural steel and pipe were to be sandblasted to white metal and sprayed with four coats of vinyl (minimum 5 mils thickness). Boiler casing and hot pipe were to be sandblasted to white metal and sprayed with three coats of activated epoxy (minimum 6 mils thickness).

Estimated cost (including markup) of this job was as follows: scaffold and clean up—.08 square foot; sandblasting (labor and material)—.16 square foot; painting (application)—.10 square foot; material (paint)—.16 square foot; total cost per square foot—.50.

The cost per square foot allocated to each operation was determined by information gained in 10 years' field experience. This arbitrary system has proven more accurate than some complicated systems. The cost per square foot above applies only to this particular job. This varies according to factors in above paragraph.

Special Coatings and Linings

Special coatings and linings were overlooked in the original program outlined to management. They have been an important factor in the fight against corrosion and should be considered in planning any coating program.

The following special coatings and linings were used to protect steel and concrete surfaces especially in tank and pipe interiors: PVC linings and coatings, baked epoxy coatings, modified epoxy coatings, phenolic coatings and 100 percent solid epoxy coatings.

Accomplishments of Program

The accomplishments listed below indicate a tremendous progress over the past four years. These accomplishments were not accidental but the direct result of a carefully planned and properly executed paint program.

The most important accomplishment was management's acceptance of the entire program as outlined. One year was required to gain the confidence and to prove to management that a complete change in operations was not only desirable, but necessary to achieve the objectives they desired.

Community Relations

Visiting salesmen, people in adjacent towns and plant employees often comment about the difference in plant appearance after the painting program was begun. The clean, pleasing look also has helped the safety and good housekeeping programs. This is an asset that can not be measured in dollars and cents.

Expected Coating Service Life

The program is still too young for accurate predictions of maximum service life of coatings. Installations three to four years old are still in almost perfect condition. The roughest installation was in Thorne Bleach which was coated in 1955 with four coats of vinyl over a disc-sanded surface. This is still about 96 percent perfect, and indications are that a service life of six years will be attained before recoating is necessary.

The coating systems are holding up so well that inspection period may be extended from one to two years. Except in minor cases on sharp edges and around some rivet or bolt heads, no failures have occurred on any of the major installations since 1956.

In the most severe areas there has been no surface deterioration of the vinyl or the epoxy coatings. A minimum life of six years can be expected. The second paint cycle should require only touch-up of damaged and failing areas plus an over-all coat to extend the life of the coating another six years or more.

Costs

The average cost from 1955 to 1956 was 50 cents a square foot. From 1956 to 1959 this cost dropped to approximately 36 cents. This was achieved through better organization, training program, better equipment, more efficient use of equipment and materials and better supervision. In many cases this cost is based on three- and four-coat systems which were necessary because of the condition of old surfaces. This will not be necessary on the next painting cycle.

Purchasing and Warehousing

Close cooperation between purchasing, stores and the painting department has resulted in the following benefits:

1. Selection of single suppliers and minimum generic types decreased the paper work in purchasing and stores.

2. Enabled purchasing to obtain lower prices on materials because of increased volume.

3. Stores has reduced stock level approximately 72 percent in three years.

4. Reduced loss in materials due to long storage life and partial cans left over from completed jobs.

Records and Reports

Management is now aware of the true status of their painting. This was made possible through a simple record system which accumulated all information on completed work, future work, preventive maintenance and inspection. These records serve as basis for projecting painting cost and other pertinent information which is submitted monthly to all interested departments.

Production and Quality

The most significant and gratifying achievement since the inception of this program has been the improvement in production and quality of painting. It is sometime difficult to greatly increase production without lowering work quality. This has been accomplished through close supervision and careful inspection coupled with continuous on-the-job training. This training stresses not only how to do a job but also reasons why the job

is to be done a particular way. Supervision and labor must be sold on the methods and procedures or success will be limited.

Conclusion

The execution of this program has not been achieved without difficulties. Many years of established practices and customs can instill prejudices and problems difficult to overcome. It has been a slow, tough road and will require increased vigilance and planning not only to hold the ground gained but to better the future performance. Nevertheless management believes the results so far justify the time and money spent.

DISCUSSIONS

Comments by Lt. Col. Serge Tonetti, U. S. Army Chemical Corps, Sheffield, Alabama:

Was surface preparation and all coating work accomplished on the ground prior to erection for new construction?

Reply by M. W. Belue, Jr.:

No. Original job specification called for sandblasting to white metal, prime coat and intermediate coat to be accomplished before erection. Welds and damaged areas to be cleaned and spotted after erection and then two finish coats to be applied.

Comments by E. G. Brink, American Viscose Corp., Marcus Hook, Pa.:

(A) If you did not have any cost data on your old painting program, how did you determine what savings could be effected by going to an improved painting program?

(B) What was the average dry film thickness of the coating system used in your maintenance coating program?

Reply by M. W. Belue, Jr.:

(A) Records were kept from April, 1955 to April, 1956. Costs from these records were compared with estimated costs based on 9 years personal contract paint experience. Management accepted these figures. Three years' experience from 1956 to 1959 proved them to be fairly accurate.

(B) 5 mils.

Comments by Ed W. Oakes, Houston, Texas:

Does your cost analysis break down the cost of surface preparation as against the cost of coatings and their application?

Reply by M. W. Belue, Jr.:

The following costs are per square foot: surface preparation including sand, etc., 16 cents; paint (vinyls and epoxies), 16 cents; paint application, 10 cents; rigging and staging, 3 cents; and sand removal, 2 cents. Total costs given are 53 cents per square foot.

Any discussion of this article not published above will appear in the December, 1959 issue

Four-Tower Water Treatment Test Facility*

By R. G. MURRAY and M. E. TESTER

Abstract

A four-tower water treatment test facility was built for the study of corrosion in copper condenser tubes. A two-by-two factorial experiment was run using phosphate treated water at two levels of water velocity and two water temperatures. The system was operated continuously for ninety days after which the tubes were removed for inspection. After being split open, the tubes were visually inspected for pitting corrosion. Pits were found in the tubes from the two towers operating at low water velocity; these pits were more severe in the high temperature units. Silt deposits were much less in the low temperature, high velocity unit than in the other units. Results indicate it is possible to simulate plant conditions in the laboratory. 7.4.2

Introduction

BECAUSE of the serious pitting corrosion evident in the water side of the Freon condenser tubes of the Goodyear Atomic Corporation water circulating system, various tests have been conducted. Some were long-term tests under actual plant conditions; others were short-term laboratory tests designed to cover a wide variety of conditions and materials. In none of the tests, however, had accurate measurement of sample variations been possible. Moreover, it had not been demonstrated conclusively that plant operating conditions could be reproduced in a controlled laboratory situation. The four-tower water test facility described here was constructed for a study of the chemical and physical factors which produce pitting corrosion of copper tubing. Its design, it was hoped, would provide for accurate measurement of sample variations. The performance of the system indicates that it will be a valuable instrument in the further study of corrosion. Subsequent tests are planned in which various corrosion inhibitors will be used.

Description of the Test Facility

The test facility is constructed for flexibility in the selection of variables: Water temperature, water velocity and type of corrosion inhibitor. The system comprises four identical redwood cooling towers, each four feet long, two feet wide and six feet high. The towers can be operated individually, as two groups, or in a single combination.

Each tower is equipped with a steam chest containing a sample manifold with four copper tubes. The tubes are 3-foot sections of finned copper condenser tubing of 0.75-inch outside diameter. These are soft-soldered into the sample chest. Figure 1 shows the towers, 1000-gallon make-up-water tank, the industrial pH meter and the pulsafeeder sulfuric acid supply pump. A 60-gallon holding tank is behind the sample chamber and cannot be seen in the photographs. The tanks are made of hot rolled-steel plate with welded seams. All piping and fittings in the system are made of steel. Figure 3 shows the flow pattern for the four-tower system.

Only one circulating pump was used in the first run; however, three between-tower pumps were installed after the run was completed to make possible a closer control of pH and total solids in subsequent tests.

Operation of the System

The four towers were used as a single recirculating system, each being subjected to a different combination of controlled temperature and water velocity. Temperatures of 110 and 130 F and water velocities of two and six feet per second were maintained. Water for the 1000-gallon raw-water tank was brought from the water treatment plant by truck. The water flows from the holding tank to the pump inlet. In each tower, before entering the sample holder inlet, the water passes through an orifice so that the flow rate may be measured. Entering the manifold at the left, it is distributed to

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MARVIN E. TESTER—In the Laboratory Division of the Chemical and Process Engineering Departments of Goodyear Atomic Corp., Portsmouth, O. since 1955, his principal field of activity is in aqueous corrosion of copper and steel and the study of water treatment facilities. He has attended both East Tennessee State College and the Universtiy of Tennessee.

★ Submitted for publication November 14, 1958. The work reported herein performed under Contract AT-(33-2)-1 with the United States Atomic Energy Commission.

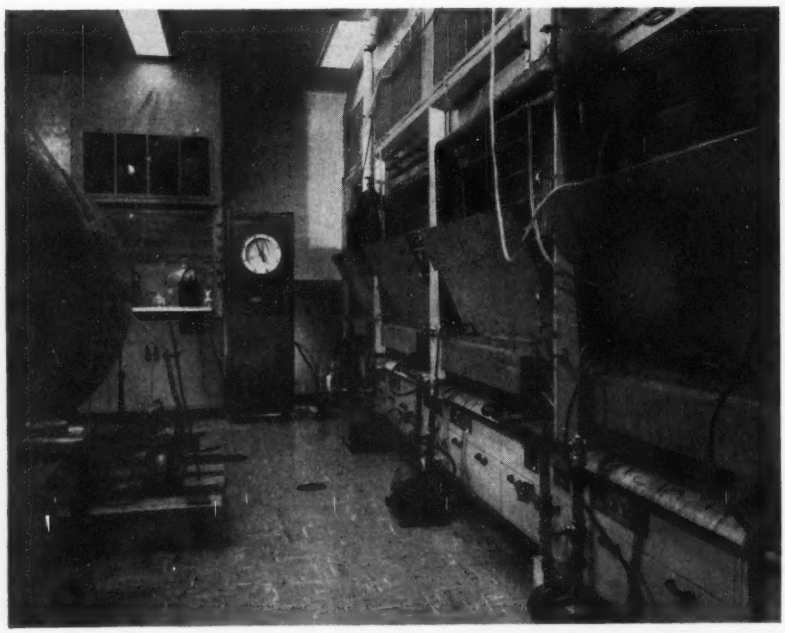


Figure 1—Four-tower laboratory test facility.

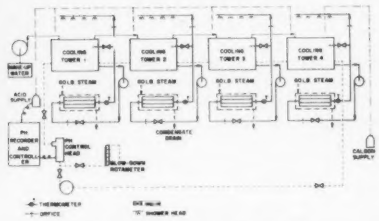


Figure 2—Flow pattern for system.

the four sample tubes. It then passes from the manifold outlet at the right and up through the vertical pipe at the right side of the tower to shower heads spaced across the top.

A bypass provides for control of tower temperature by allowing part of the hot water to flow directly into the holding tank. Flow through the shower heads is indicated by a mercury manometer tapped in across an orifice located in the vertical riser.

Tubes are heated by low-pressure steam conducted into the sample chest at the left end, the condensate being drained at the other end. Water temperature can be controlled by adjustment of the steam valve. The system between-tower circulating rate during the run was approximately two gallons per hour. The rate, which was dependent on tower-to-tower flow, could be maintained with a two-inch difference between the levels of the holding tanks of the first and the last towers. A blowdown line is located between the pH head and the first tower, the rate of blowdown being measured by a rotameter. Sulfuric acid was added to each tower through furfural resin tubing with the flow adjusted to maintain a 5.8 to 6.2 pH range on the recorder.

Physical and chemical conditions were selected to simulate the most corrosive conditions which could occur at start-up of the plant recirculating water system. These were low pH, low water velocity and high temperature difference between water and condensing vapor. The raw-water storage tank under each tower was filled to operating level and sodium phosphate was added until there were 15 parts per million. A one-percent solution of sulfuric acid was added until a pH of 6 was obtained. The pumps were then started and the flow rates adjusted to the desired operating conditions. Desired water temperatures were obtained through operation of the steam valves. After the system reached equilibrium, continuously operating equipment was started for feeding of sulfuric acid solution and sodium phosphate solution.

The sulfuric acid solution was added at the rate of 7 liters per day, the sodium phosphate (unadjusted sodium phosphate glass) at the average rate of 3 liters per day of 1 percent solution. The 1000-gallon storage tank was refilled every third day. Concentration of dissolved solids was maintained by adjustment of continuous blowdown at three times the make-up level to simulate solid build-up in the actual plant system. Table 1 shows temperatures and velocities maintained during the run.

Five water samples were submitted each day for analysis, one of the five samples being a control for making bias and precision estimates. Determinations were made of pH, total hardness, total solids, and amount of calcium, magnesium, metaphosphates and ortho-phosphates. Each month a complete water sampling was made. Appendix 1 shows typical data collected. After 89 days of operation, the system was shut down and the copper tubes were removed. Tubes were marked to indicate the number of the tower from which they were taken, their location in the manifold, the direction of the water flow and top and bottom. Steel piping was removed between towers because of heavy scale. No appreciable corrosion was noticed.

TABLE 1—Operating Conditions Maintained

Tower No.	Velocity ft/sec	Copper Tube Outlet °F	Holding Tank °F
1	6	130	115
2	6	110	105
3	2	130	115
4	2	110	105

Inspection of Copper Tubes and Steel Piping

Copper Tubes

A 12-inch section was cut from the inlet end of each copper tube and weighed before and after cleaning to measure silt deposits. The entire length

TABLE 2—Effect of Water Temperature and Velocity on Silt Deposit and on Corrosion of Copper Tubes

Tower No.	Outlet Temp. °F	Velocity ft/sec	Silt Weight g/ft	Type of Corrosion
1	130	6	2.69	Superficial
2	110	6	0.36	Superficial
3	130	2	3.00	Pit and surface attack
4	110	2	2.35	Pit and surface attack—less severe than in Tower No. 3

APPENDIX 1—Typical Data From Conditioning Department Analysis of Water Samples (Results mg/1)

ANALYSES	Type of Water						
	Raw	Makeup	Tower 1	Tower 2	Tower 3	Tower 4	Control Sample‡
p^H	8.0	9.7	6.8	6.5	6.4	6.2	6.4
Specific Conductance – Micromhos per CM^2 at 25°C.	521	645	1639	1613	1639	1818	1136
Total Solids	456	336	1495	1347	1496	1490	897
Dissolved Solids	430	314	1430	1305	1474	1485	889
Suspended Solids*	26	22	65	42	22	5	8
Total Hardness as $CaCO_3$	341†	125†	358	354	389	394	224
Calcium Hardness as $CaCO_3$	196†	36†	119	126	132	133	75
Magnesium Hardness as $CaCO_3$*	145†	89†	239	228	257	261	149
Carbonate Alkalinity as $CaCO_3$	0†	49†	0	0	0	0	0
Bicarbonate Alkalinity as $CaCO_3$	214†	28†	14	10	9	9	7
Hydroxide Alkalinity as $CaCO_3$	0†	0†	0	0	0	0	0
Chlorides	42†	52†	182	178	183	189	130
Total Soluble Phosphates	0.9	0.3	91.5	89.2	84.6	86.5	55.3
Ortho Soluble Phosphates	0.7	0.1	16.9	16.8	16.1	16.4	10.3
Meta Soluble Phosphates*	0.2	0.2	74.6	72.4	68.5	70.1	45.0
Total Zinc (Polarograph)	0.1†	0.2†	0.1	0.0	0.2	----‡	0.3
Soluble Zinc (Polarograph)	0.0†	0.0†	0.1	0.0	0.0	0.1	0.0
Sulfates	117	103	470	504	622	637	388
Silica	8	0	15	17	16	17	14
Copper	0.04	0.03	0.09	0.10	0.10	0.11	0.8
Soluble Iron	0.12	0.17	0.9	2.0	1.8	2.3	1.7
Soluble Synthetic Detergents	0.19†	0.21†	-----	-----	-----	-----	-----
Chromium (Cr^{+6})			0.0	0.0	0.0	0.0	0.0
Fluoride	0.6	0.5	-----	-----	-----	-----	-----

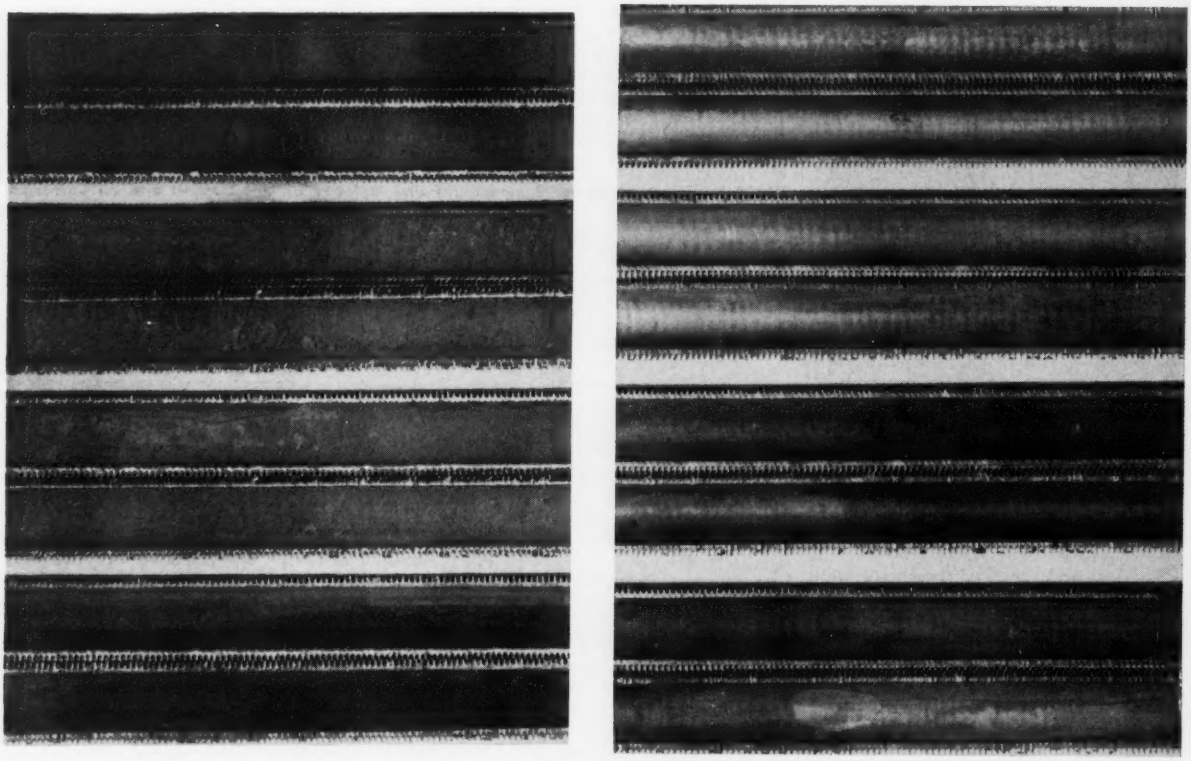
*By mathematical difference.
†Average of duplicate determinations.
‡Unable to obtain satisfactory value.
‡Taken from Tower 2 and diluted with distilled water to 60 percent of its original strength.

APPENDIX 2—Corrosion and Silt Deposits

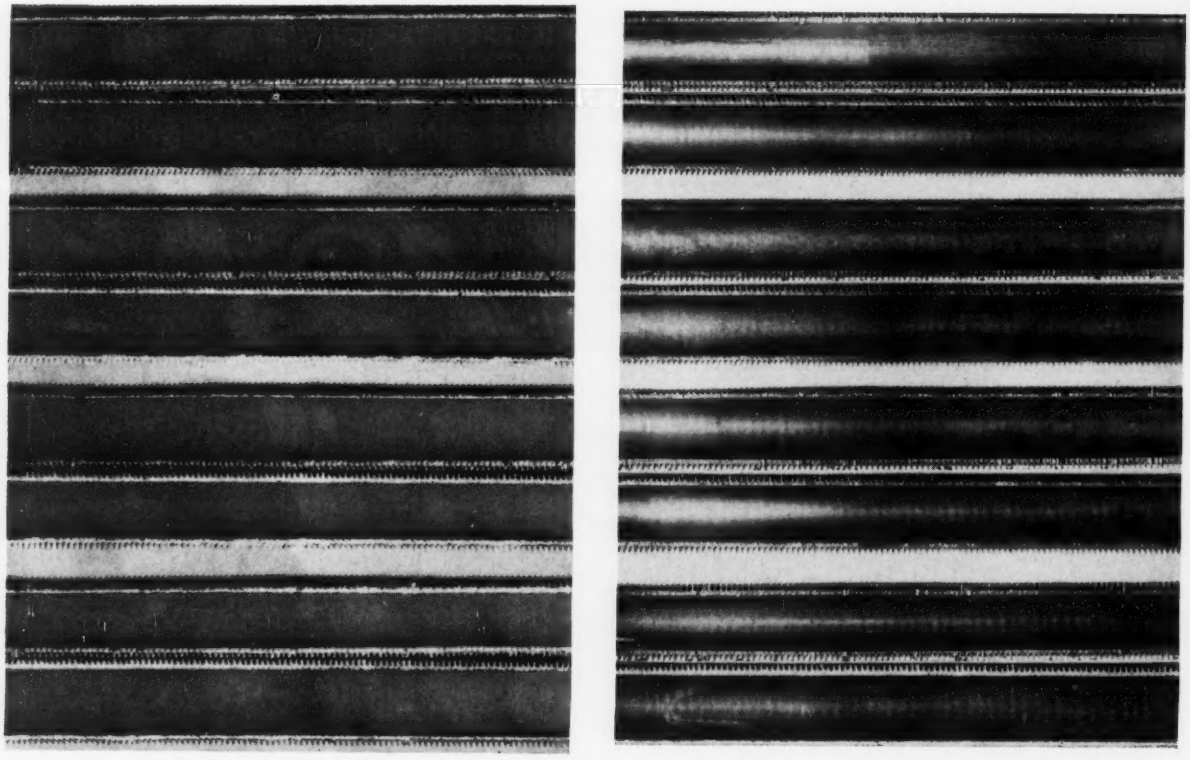
Shown below are photographs of 6-inch sections of all tubes used in the test. They are in A,B,C,D order (See Appendix 3) with the top half of each tube at the top. Positions correspond to positions in the steam chest.

BEFORE CLEANING

AFTER CLEANING



TOWER 1



TOWER 2

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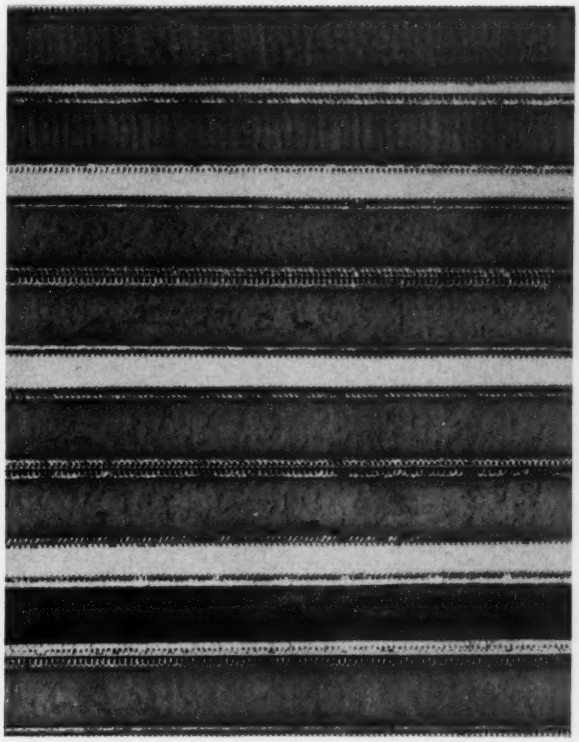
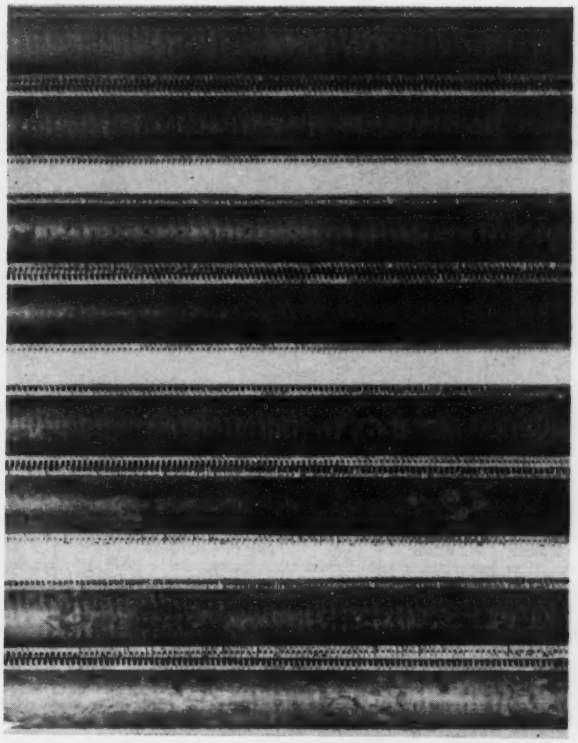
APPENDIX 2—Corrosion and Silt Deposits—Continued

Shown below are photographs of 6-inch sections of all tubes used in the test. They are in A,B,C,D order (See Appendix 3) with the top half of each tube at the top. Positions correspond to positions in the steam chest.

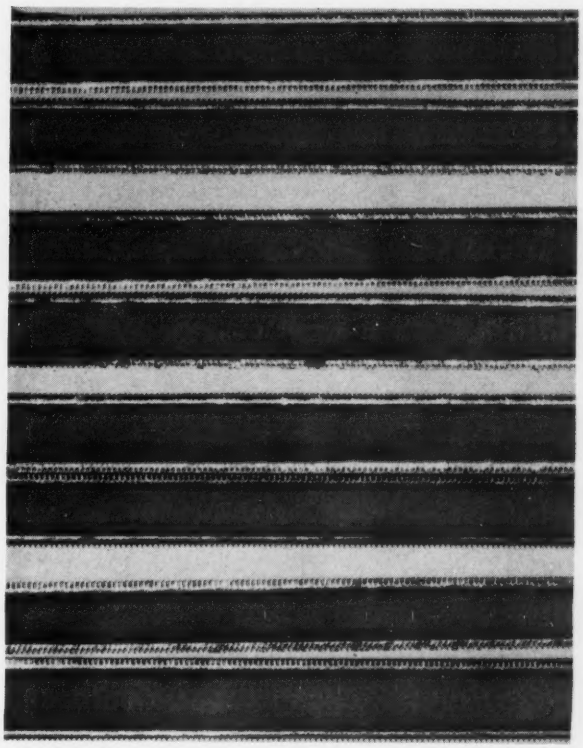
BEFORE CLEANING

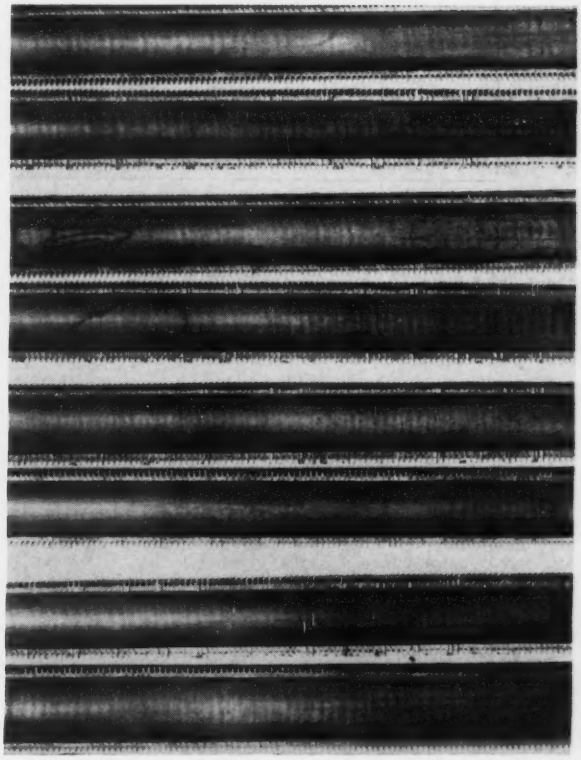


AFTER CLEANING



TOWER 3





TOWER 4

495t

of each tube was inspected by the metallurgy department for type and severity of corrosion and photographs were made (see Appendix 2).

Steel Piping

Samples of the steel piping were cleaned electrolytically and then photographed and inspected by the metallurgy department. The between-tower steel piping which has been removed contained substantial silt deposits, but little evidence of corrosion was visible.

Results

Average weight of the silt deposits and the degree of corrosion are summarized in Table 2. More complete data appear in Appendix 3.

An examination of the data collected revealed that pitting corrosion developed only in the tubes subjected to low water velocity. Pitting was most severe in the high-water-temperature unit. The amount of silt deposited was dependent upon both water temperature and water velocity with some indication that temperature was the most important factor. No correlation was evident between the amount of silt deposited and the severity of the pitting.

Conclusions

The following statements can be made on the basis of the data collected during the two tests:

1. Plant operating conditions can be simulated in the laboratory and control can be maintained.
2. Statistical results are significant: Within-tower sample differences were much smaller than tower-to-tower sample differences.
3. Pitting corrosion was found only in copper tubing subjected to water of low velocity. It was more severe in the high than in the low temperature unit.
4. Most silt appeared in the low-velocity, high-temperature unit with indications that temperature was the more important factor.
5. There seems to be no correlation between the amount of silt deposited and the severity of the pitting.

APPENDIX 3—Results of Inspection for Corrosion* and Silt Deposits†

Tower	Tube Top and Bottom		Type of Corrosion	Weight of Silt
1	A	T	Corrosion with slight penetration	–
		B	Same	–
	B	T	No noticeable corrosion	1.46
		B	Same	1.40
	C	T	Discolored spots	1.66
		B	Same	1.67
	D	T	Numerous spots of corrosion	1.29
		B	Discolored spots	.96
2	A	T	Superficial corrosion	.11
		B	Same	.15
	B	T	Superficial corrosion (Tubercles)	.19
		B	Same	.20
	C	T	Shallow pitting	.24
		B	Same	.23
	D	T	Superficial corrosion	.22
		B	Surface corrosion	.17
3	A	T	Surface attack	–
		B	Shallow pitting < .005-in	–
	B	T	Spots of corrosion	1.38
		B	No noticeable corrosion	1.52
	C	T	Shallow and deep pitting	1.87
		B	Discolored spots	1.90
	D	T	Surface corrosion	1.48
		B	Same	1.37
4	A	T	Possible surface attack	1.37
		B	Same	.91
	B	T	No noticeable corrosion	1.18
		B	Same	.74
	C	T	Deep pitting [.010-in	1.48
		B	Shallow pitting	1.69
	D	T	Numerous spots of corrosion	1.00
		B	Same	.78

* Visual inspection for corrosion made after deposits were washed off with water and a stiff brush. A ten-power binocular microscope was used.
† A one-foot section was cut from the inlet end of each tube, split into top and bottom, and weighed after cleaning. One foot of tube weighed approximately 200 g. before cutting. Weight of silt is in g. of silt per 100 g. of tube.

Revised 11-21-58

Any discussion of this article not published above will appear in the December, 1959 issue

Use of Magnesium for Cathodic Protection Of Pipe Lines in High Resistivity Soil★

By A. W. PEABODY

Abstract

A cathodic protection installation is described in which satisfactory protective potentials were attained on approximately 400 miles of enamel coated pipeline with a total current between two and three amperes from nine magnesium anode beds. Over-all current consumption was less than 0.5 microamp per square foot. Average soil resistivity at pipeline depth was 120,000 ohm-cm although it dropped to less than 2000 ohm-cm at potential hot-spots. Indicated average coating resistance for the system was about 700,000 ohms per average square foot. Four of the nine anode installations were in soil having resistivity above 10,000 ohm-cm.

Methods are described in which long slender magnesium anodes were used to obtain the necessary current output. Testing facilities and zinc anode electrolytic cells for protection against lightning or electric power surges are also described. 5.2.2

Introduction

OPERATING EXPERIENCE has shown that in areas of predominantly high soil resistivity, commonly thought to restrict damaging corrosion, there is usually a sufficient degree of variation in soil composition and resistivity to cause serious damage to pipelines traversing such areas. For this reason South Georgia Natural Gas Company incorporated plans for complete corrosion control with coatings and cathodic protection when designing their transmission system. This system includes approximately 400 miles of pipeline, ranging from 12-inch to 2-inch, in Alabama, Georgia and Florida.

After a preliminary survey, the decision was made to utilize a galvanic anode cathodic protection system using magnesium anodes even though the average soil resistivity at pipeline depth on this system was in the order of 120,000 ohm-cm. This paper is concerned with the design problems involved in the preparation of plans for this system as well as a review of the results that were obtained. Possibly the most significant performance feature was the attainment of protective potentials on the 400-mile system with only nine magnesium anode installations (seven of which were in soils ranging from 11,500 to 52,000 ohm-cm resistivity) for an average current consumption of only 5.3 milliamps per mile of pipe.

System Description

The South Georgia Natural Gas Company system was made up of the lines shown in Figure 1 at the time the cathodic protection system was designed. The welded steel system was coated with a 3/32-inch layer of "standard" coal tar enamel reinforced with a glass mat wrapper pulled into the coating. Railroad and highway crossing casings were coated with a 3/32-inch coating of the standard enamel. The use of a standard enamel rather than a modified or fully plasticized material was considered satisfactory for this particular system since soils were predominantly sand or clay (no backfill damage), temperatures were not such that enamel cracking would be experienced, and the possibility of long-term damage due to soil stress was not thought to be a significant factor.

During system construction, insulated flanges were installed at convenient locations as shown in Figure 1 for use as necessary during preliminary corrosion testing as well as for operation and maintenance of the completed cathodic protection system. The transmission lines were also insulated from all city and town distribution systems served by South Georgia Natural.

Corrosion control test points were installed at the same time as the pipelines were laid. These included "calibrated" sites (test points provided for pipe-to-soil potential measurement and measurement of pipeline current in terms of voltage drop across a measured length of pipe steel) which were installed at intervals of approximately two miles at convenient road crossings or other accessible locations. At any cased crossings not having a calibrated test point, a test point for measurement of pipe-to-soil potentials was installed for convenient check of pipe potential and for determining whether or not casing pipe is properly insulated from line pipe. Test points also were provided at crossings with pipelines of other ownership and at buried insulated flanges. Construction of the piping network shown on Figure 1 was completed in the Fall of 1955.

Need for Cathodic Protection

Although this system is in an area where soil resistivities are predominantly high, utilities operating in other sections of the general area have reported serious corrosion damage on steel systems. An example of this is discussed by Van Noughuys[1] for a bare system which is in this same general high soil resistivity area. This system was reported as developing leaks at a serious rate within nine years after completion. Even though the average soil resistivity was high, there was, nevertheless, sufficient variation from point to point along the system to indicate the presence of anodic and cathodic areas. In earlier days of pipelining, it was often assumed that even though such conditions might exist, the actual amount of corrosion current flowing would be so restricted by the high soil resistivity that many years would pass before any significant damage could develop.

Experience of other companies operating in South Georgia Natural area has shown that this cannot be depended on and that leaks may develop in a surprisingly short time. There are at least two reasons why this can be possible. The first of these is that the anodic sections, or "hot spots," may be fewer and smaller in area than on comparable lines in soils of much lower average soil resistivity. This condition would result in a concentration of current discharge that would tend to offset the constraining effect of the high soil resistivity.

A second possibility is that of higher driving potentials in the corrosion circuits (i.e., larger voltages existing between soils in anodic and cathodic areas than would be found on many comparable lines in low average resistivity soils generally considered corrosive). This may be somewhat allied with the ratio of highest resistivity soils to lowest resistivity soils. This ratio can be much higher on a pipeline traversing an area of predominantly high resistivity soils than on one passing through an area of generally low resistivity corrosive soils. Higher driving potentials in any given anode-cathode corrosion circuit would tend to offset the restricting effect of the

About the Author

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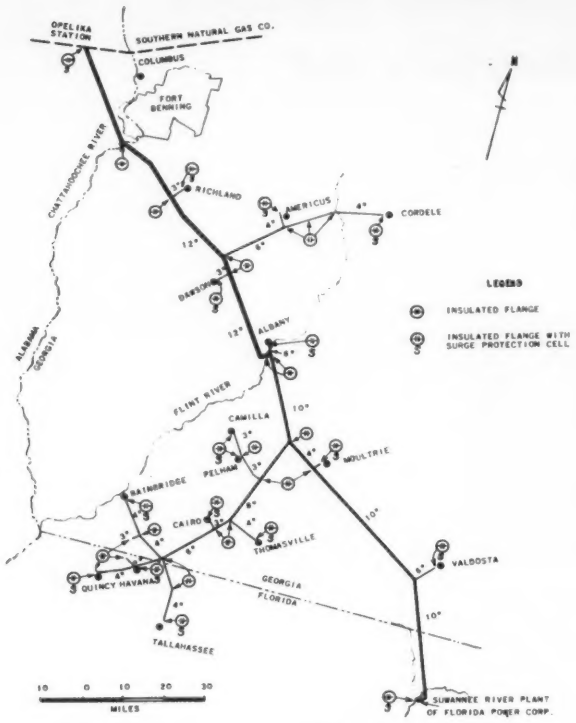


Figure 1—Pipeline system of South Georgia Natural Gas Company.

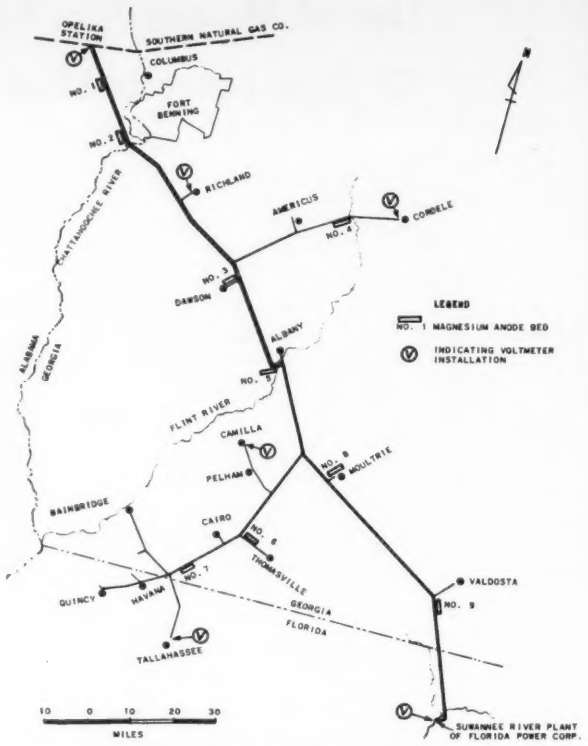


Figure 2—Location of corrosion control installations.

TABLE 1—Summary of Soil Resistivity Measurements

Depth, Ft.	Soil Resistivity in Ohm-Centimeters		
	Lowest Reading	Highest Reading	Average
2.5.....	3,200	500,000	100,000
5.0.....	3,700	1,000,000	117,000
7.5.....	1,600	900,000	88,000
10.0.....	1,900	800,000	80,000
15.0.....	1,700	930,000	103,000

Fifty three sets of readings represented. Resistivities recorded are average values to indicated depths. Wenner method was used.

higher soil resistivities and contribute to early corrosion failures. As an example, the ratio of highest to lowest resistivity soils measured throughout the company's system was approximately 625 whereas the comparable ratio for a 400-mile section of line in the corrosive soils of South Texas, for which a substantial file of soil resistivity measurements are available, was only about 170. The readings from which this latter ratio were determined were predominantly low whereas those from which the former ratio was determined were mostly high.

Preliminary Corrosion Survey

Prior to determining the cathodic protection system that would be used, a field survey was undertaken to accumulate data to serve as a basis for an engineered protective plan. The survey included measurements of soil resistivities throughout the system, measurement of the effective pipe coating resistance, making current requirement tests, checking condition of insulation between casing and carrier pipe at cased crossings, checking the effect of stray d-c current, and checking the need for any additional grounding that might be required along one section of the line paralleled by high voltage electric transmission lines.

Soil resistivity measurements were made by the Wenner method. Table 1 summarizes the data obtained. It will be noted from the table that the average of all readings to a depth of five feet (representative of conditions at pipe depth) is 117,000 ohm-cm which is a high value for a system of this size. This is significant in that the apparent coating resistance along the line could be expected to be appreciably higher than that of a line having the same quality coating in soils of lower average resistivity. This could be expected to result in lower than usual current per unit area to attain satisfactory protective potentials. Offsetting the advantage of lower expected current requirement for protection, the high soil resistivities meant difficulty in getting the necessary current into the earth.

Data for approximate coating resistance calculations as well as determination of current requirements for protection were obtained by applying battery current, periodically interrupted, to sections of the system between points of insulation. Apparent coating resistances were calculated from average voltage change (ΔV) along the section of line under test caused by the interrupted current (ΔI) drained from the section. Table 2 summarizes the coating resistance data obtained and includes estimates of the current requirements for cathodic protection based on the coating information. Although the indicated coating resistances on individual sections of the system ranged from a low of 57,000 to a high of 1,900,000 ohms per average square foot, the lower readings were on relatively short sections. The weighted average for the entire system was approximately 700,000 ohms per average square foot.

Using the coating resistance values, one method of approximating the current requirements for cathodic protection is to calculate the current necessary to maintain an average potential drop of 0.2 volt across the coating in each section for which the coating resistance had been determined. An approximation of this type assumes current sources sufficiently distributed along the system being protected such that attenuation in the lines will not be a major factor. The figure obtained will not necessarily be the precise current applied from the actual installations but it will indicate the general order of current that will be needed. Estimated current requirements for each section as shown in Table 2 were calculated by this method. The indicated total is about 1.6 amps for the system whereas the actual current drained by the protection system when installed was just over 2.0 amps.

With the information available from the preliminary survey, the following

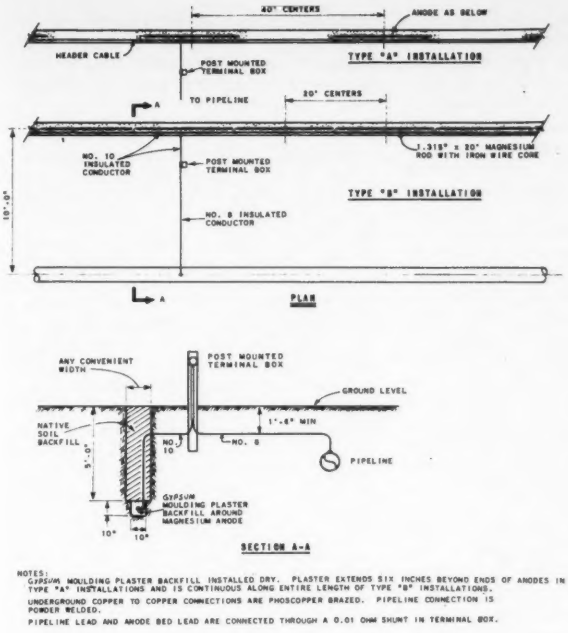

40' CENTERS
ANODE AS BELOW
HEADER CABLE
POST MOUNTED TERMINAL BOX
TYPE "A" INSTALLATION
TO PIPELINE
20' CENTERS
1.315" x 20' MAGNESIUM ROD WITH IRON WIRE CORE
NO. 10 INSULATED CONDUCTOR
POST MOUNTED TERMINAL BOX
TYPE "B" INSTALLATION
NO. 8 INSULATED CONDUCTOR
PLAN
ANY CONVENIENT WIDTH
POST MOUNTED TERMINAL BOX
GROUND LEVEL
NATIVE SOIL BACKFILL
1'-6" MIN
NO. 10
NO. 8
PIPELINE
GYPSUM MOULDING PLASTER BACKFILL AROUND MAGNESIUM ANODE
SECTION A-A
NOTES:
GYPSUM MOULDING PLASTER BACKFILL INSTALLED DRY. PLASTER EXTENDS SIX INCHES BEYOND ENDS OF ANODES IN TYPE "A" INSTALLATIONS AND IS CONTINUOUS ALONG ENTIRE LENGTH OF TYPE "B" INSTALLATIONS.
UNDERGROUND COPPER TO COPPER CONNECTIONS ARE PHOSCOPPER BRAZED. PIPELINE CONNECTION IS POWDER WELDED.
PIPELINE LEAD AND ANODE BED LEAD ARE CONNECTED THROUGH A 0.01 OHM SHUNT IN TERMINAL BOX.

Figure 3—Installation detail for magnesium anode beds.

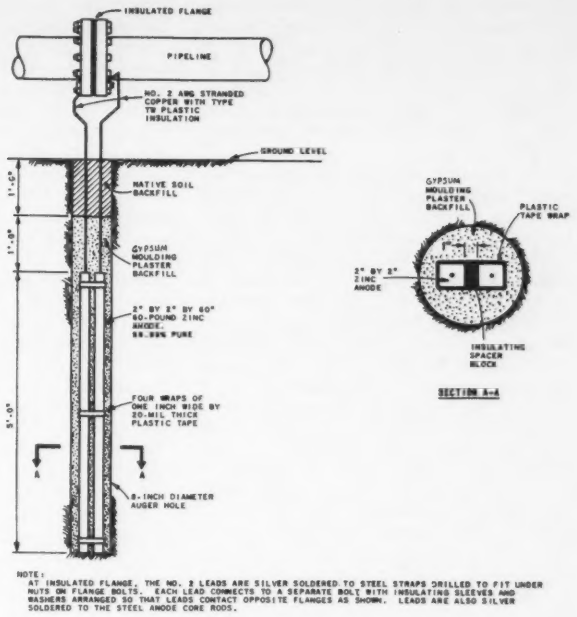

INSULATED FLANGE
PIPELINE
NO. 2 AWG STRANDED COPPER WITH TYPE TW PLASTIC INSULATION
GROUND LEVEL
NATIVE SOIL BACKFILL
GYPSUM MOULDING PLASTER BACKFILL
2" BY 2" BY 60" 60-POUND ZINC ANODE. 99.99% PURE
FOUR WRAPS OF ONE INCH WIDE BY 20-MIL THICK PLASTIC TAPE
8-INCH DIAMETER AUGER HOLE
GYPSUM MOULDING PLASTER BACKFILL
PLASTIC TAPE WRAP
2" BY 2" ZINC ANODE
INSULATING SPACER BLOCK
SECTION A-A
NOTE:
AT INSULATED FLANGE, THE NO. 2 LEADS ARE SILVER SOLDERED TO STEEL STRAPS DRILLED TO FIT UNDER NUTS ON FLANGE BOLTS. EACH LEAD CONNECTS TO A SEPARATE BOLT WITH INSULATING SLEEVES AND WASHERS ARRANGED SO THAT LEADS CONTACT OPPOSITE FLANGES AS SHOWN. LEADS ARE ALSO SILVER SOLDERED TO THE STEEL ANODE CORE RODS.

Figure 4—Detail of surge protection cell.

points were some of those most pertinent to the selection of a sytem to provide the necessary protective current:

1. Very small amount of current needed for protection in view of system size.

2. High average soil resistivity with very few locations having even moderately low soil resistivities.

3. Power lines not available at some sites where installations could be made.

4. Desirability for the least possible maintenance requirements on the system installed.

Even though most of the installation sites available (where lower-than-average soil resistivity had been found) had soils of substantially higher soil resistivity than normally considered suitable for magnesium anodes, it was decided that sufficient protective current could readily be obtained by using a reasonably small number of anode beds. It was recognized, however, that modifications in the usual type of anode installation would have to be made to obtain a practical amount of current output.

TABLE 2—Summary of Coating Resistance Measurements and Estimated Current Requirements for Cathodic Protection

Line No.	Pipe Size, Inches	Pipe Length, Miles	Coating Resistance, Ohms Per Average Sq Ft	Estimated Current to Protect Section, Amps
1	12	102.9	467,000	0.775
2	10	91.1	1,050,000	0.258
3	8	26.01	900,000	0.069
4	6	20.76	840,000	0.045
5	2	4.45	121,000	0.024
6	6	16.79	394,000	0.078
7	3	3.53	139,000	0.025
8	6	5.0	643,000	0.014
10	4	2.98	343,000	0.011
11	6	8.1	446,000	0.033
12	3	5.75	1,900,000	0.003
13	3	7.5	945,000	0.008
14	4	7.63	1,060,000	0.009
15	3	2.0	735,000	0.003
16	4	18.2	1,150,000	0.031
17	4	3.1	466,000	0.008
18	6	15.46	827,000	0.034
19	4	15.19	460,000	0.041
21	2	2.2	193,000	0.008
23	4	1.62	57,000	0.035
24	4	27.04	394,000	0.086
Merck Lateral	4	.1	210,000	0.001
Total	..	.....	.....	1.599

Protection System Installed

In order to obtain reasonably high current output per unit weight of magnesium used, the designs adopted utilized long slender anodes (1.3-inch diameter by 20 feet long) of extruded magnesium. These anodes were best adapted to horizontal anode bed construction. Horizontal construction was in general suited to the usual pattern of soil stratum occurrence in which high resistivity materials were found underlying the surface layers in which anodes could be placed with the normal type of construction. Nine locations were selected for installation of anode beds. The locations of the nine sites around the system are shown on Figure 2.

There were two types of anode distribution used. Type "A," used in the higher soil resistivities, consisted of the 20-foot long anodes placed horizontally on 40-foot centers along and in line with the ground bed route. Type "B," used at locations of lower soil resistivity, consisted of the 20-foot long anodes placed end to end. Anode bed lengths ranged from 380 to 428 feet. Gypsum moulding plaster was used as a backfill in both types of installation. Backfill extended 6 inches beyond the end of each anode in the Type "A" installation but was continuous for Type "B." In cross section, the backfill occupied a 10″ x 10″ area with the anode centered therein. Figure 3 illustrates the general anode arrangement for Types "A" and "B"' installations and shows the terminal facilities used.

Gypsum moulding plaster used as a backfill has a resistivity in the order of 1000 ohm-cm. Since this resistivity is low as compared to that of the surrounding backfill at most of the installation sites and since a large cross-section area was used relative to the cross-section area of

the anodes, the effect of any variations in soil resistivity along the length of an anode (which would otherwise result in uneven attack on the anode) should be largely eliminated. This is particularly desirable when using long, slender anodes to ensure uniform consumption and longest effective life.

The gypsum moulding plaster was installed dry. After taking up moisture from the soil, this material sets up hard but remains low in resistivity as long as it remains moist. The advantage of using gypsum moulding plaster on this particular system, rather than the more common backfill mixture used with magnesium, is reduction of any tendency for leaching away of the backfill in the loose sandy soils encountered at installation sites. In addition to the points discussed above, the backfill performs the normal function of improving anode efficiency by surrounding the magnesium with a uniform environment to reduce local action. Also, the large cross-sectional area of backfill used in the designs described has the effect of increasing the effective anode diameter with accompanying reduction in the resistance-to-earth of the completed anode beds.

Table 3 contains data on the nine anode beds. It will be noted that the soil resistivity data had indicated that only two of the nine sites had less than 10,000 ohm-cm soil at anode depth. An additional three sites had soil below 10,000 ohm-cm at 100-foot depth which could be expected to have some effect on the resistance-to-earth of the anodes installed in the higher resistivity upper layers. Four of the nine beds were at locations where no soil resistivity less than 10,000 ohm-cm was found at any depth. Although the anode bed resistances shown in the table are not entirely consistent with indicated soil resistivities at anode depth, the higher resistance values were obtained at the four sites where the higher over-all soil resistivity pattern was found.

Under the same contract let for installation of the magnesium anode beds, zinc anode surge protection cells[2] were installed across insulated flanges at connections with piping system of other ownership. Permanent indicating voltmeters were also installed to permit periodic checking of the voltage across such insulated flanges at key points. Points of insulation are shown on Figure 1 and the location of indicating voltmeters are shown on Figure 2.

The surge protection zinc cells were installed to prevent breakdown of insulated flanges, across which they were installed, in the event of high voltage surges resulting from lightning activity or induction from electric power systems under fault conditions. Figure 4 illustrates the type of cell installed. In operation, such cells oppose the flow of direct current (cathodic protection current) through the cell by developing a cell potential in opposition to the voltage drop across the insulated flange. This results from the ability of the zinc anode which is collecting current to readily polarize in the negative direction. Current passed by the cell is small up to potentials of about 0.4 volt drop across the insulated flange. Beyond this point, the limits of the negative polarizing ability of the zinc is reached and the cell begins to pass more current.

It is apparent, then, that where a high protective potential is attained on one side of a cell-equipped insulated flange while the system on the opposite side is unprotected, there can be some loss of protective current through the cell. In the event, however, of a high voltage surge (either a-c or d-c), the small self-developed cell potential is of no consequence and the cell passes current which limits the voltage build-up across the insulated flange. This action prevents insulation breakdown which could result in loss of protective potentials.

Cells were not required at insulated flanges other than at foreign system interconnections. Flanges within the system were provided for testing and trouble-shooting purposes only and are shorted out in normal operation.

The permanently installed indicating voltmeters at system key points were intended to serve, when read periodically, as general guides to system condition. The indicated voltage drop across an insulated flange between separate systems will be a measure of the status of cathodic protection on the system being operated as long as the potential-to-earth of the foreign system is stable and is known. It is obvious that occasional more detailed maintenance tests are desirable in order to verify the apparent condition of the cathodic protection system as given by the periodic readings of the indicating voltmeters. In general, however, any sudden change in the pattern of recorded values or a drop to zero would signify a probable change in the cathodic protection system or failure of the insulated flange. Detailed tests could then be made to determine the reason for the change.

Performance of Protection System

Installation of the nine magnesium anode beds, together with installation of surge protection cells and indicating voltmeter installations, was completed in May 1956. Table 4 contains a tabulation of the current outputs of the several anode beds after installation in 1956 and again in May 1958. The total current in 1956 shortly after completion of the system was 2.04 amps while in 1958, the total output had increased to approximately 2.42 amps. The greatest increase was at Bed No. 2 which showed an increase from 180 to 440 milliamps. Since the 180 milliamp figure was recorded within a few weeks after installation, it is believed that the gypsum moulding plaster backfill had not become completely wetted at that time. The current outputs of the anode beds are not proportional to the resistances-to-earth of the beds as measured in 1956 (values shown on Table 4). This is to be expected as differences in polarization potentials from point-to-point along the system will result in differences in driving potential at the several beds.

In terms of pipe length, the 1956 total current output of 2.04 amps represents an average cathodic protection current collection rate of approximately 5.3 milliamps per mile whereas the corresponding figure for the 2.42 amp total output in 1958 is approximately 6.3 milliamps per mile. In terms of total system pipe surface area, the 1956 average collection rate was approximatey 0.44 microamps per square foot. Based on the 1958 current output, the collection rate was approximately 0.52 microamps per square foot. These figures disregard current losses through surge protection cells at tie-ins with other systems which would operate to lower the actual collection rate on the pipeline being protected.

The current output obtained from the anode beds in 1956 resulted in excellent protective potentials throughout the system with the exception of local problems at crossings with cathodically protected bare pipelines and one stray current situation as will be discussed later. Potentials measured at the majority of the locations checked in 1958 were above —0.90 volt with reference to a copper-copper sulfate reference electrode while

TABLE 4—Current Output of Magnesium Anode Beds

Bed No.	Bed Resistance in Ohms	Current Output—Milliamps—1956	Current Output—Milliamps—1958
1	1.45	325	320
2	1.72	180	440
3	6.1	77	83
4	1.01	295	270
5	1.07	410	410*
6	0.57	280	300
7	0.67	120	160
8	...	250	310
9	5.0	104	130
Total..	...	2,041	2,423

* Installation site under water. Used 1956 figure.

TABLE 5—Estimated Life—Magnesium Anode Beds

Bed No.	Number of Anodes	Total Magnesium Weight, Lb	1958 Current Output, Amps	Life in Years* $\left(\frac{0.0493 \times \text{Lb}}{\text{Amps}}\right)$
1	10	200	0.32	31
2	10	200	0.44	22
3	10	200	0.083	> 50
4	10	200	0.27	37
5	20	400	0.41	48
6	20	400	0.3	> 50
7	10	200	0.16	> 50
8	10	200	0.31	32
9	10	200	0.13	> 50

* Based on 50 percent current efficiency and 85 percent utilization factor.

the average of readings at all such locations was —0.99 volt.

Figure 5 shows protective potentials (to copper-copper sulfate reference electrode) at system extremities as recorded in 1956 and, for comparison, potentials obtained at the same locations in 1958. As will be seen from the figure, the potentials recorded in 1958 were (with only one exception) higher than those observed in 1956 shortly after construction was completed. The general increase in protective potentials appears to be linked to the increase in the total current output of the magnesium anodes while, as discussed earlier, the output increase was probably due, in part, to more thorough wetting of the gypsum moulding plaster backfill at most of the installation sites.

Without exception (in 1958), the pipe-to-soil potentials on the South Georgia Natural side of insulated flanges at tie-ins with other systems were higher (more negative) than those on the opposite sides. The voltage drops across these flanges (each of which is equipped with a surge protection cell) ranged from 0.18 to 0.56 volt, South Georgia negative, with an average of 0.39 volt. As mentioned earlier in connection with the surge protection cells, they begin to pass appreciable current as the voltage drop across them increases beyond the polarization limitations of the zinc anodes in the cells. This condition exists at approximately half of the cell installations and contributes to the increase in total current output of the magnesium anode beds.

Local problems involved in the protection system consisted of a stray current exposure situation at the north end of the system where it connects to the source of supply as well as interference at cathodically protected bare pipelines.

The stray current situation was local in nature. After installation of the cathodic protection system (which included a surge protection cell across the insulated flange between the two systems), recording voltmeter charts revealed that protective potentials are maintained over 90 percent of the time with the unprotected periods consisting of short-term dips from a general high level of protection. Soil resistivity in the exposure area is high. This combined with the protective effect of the zinc anode surge protection cell at the insulated flange, minimizes any damaging effect.

At crossings with cathodically protected bare pipelines (two locations), protective current flowing to the bare lines resulted in potential gradients in the earth that caused the company's lines to be positive to copper sulfate electrode in the crossing area. Rather than depend on bonds between the systems at the crossing, coating was applied to the bare line a sufficient distance on each side of the point of crossing to cover the area of substantial soil potential gradient. Elimination of the high current flow in the immediate crossing area resulted in a substantial improvement of the severe exposure condition that had previously existed.

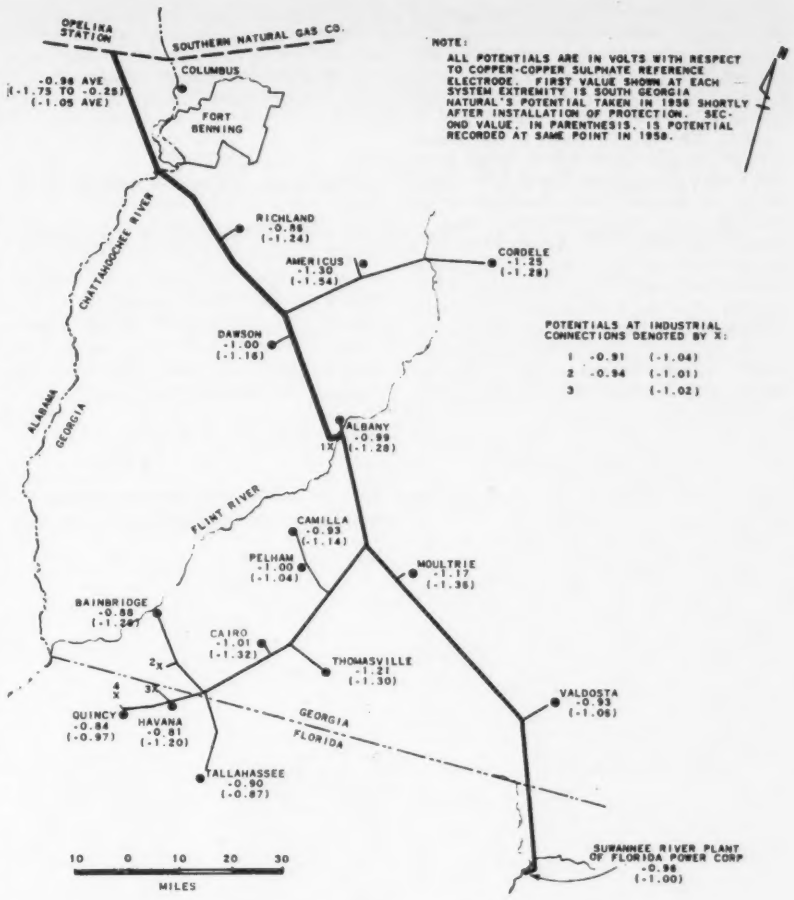


Figure 5—Protective potentials obtained with cathodic protection.

TABLE 3—Data on Magnesium Anode Beds

Bed No.	Average Soil Resistivity to 5 Ft Depth, Ohm-Cm	Lowest Soil Resistivity at Site		Bed Type	Number of Anodes	Bed Length, Ft	Bed Resistance in Ohms
		Value, Ohm-Cm	Depth, Ft				
1	12,000	10,000	2.5	A	10	428	1.45
2	16,000	16,000	5.0	A	10	393	1.72
3	23,000	21,000	7.5	A	10	380	6.1
4	14,000	6,000	100.0	A	10	380	1.01
5	3,700	3,200	2.5	B	20	400	1.07
6	4,000	1,600	7.5	B	20	415	0.57
7	11,500	6,000	100.0	A	10	380	0.67
8	28,000	1,400	100.0	A	10	390	...
9	52,000	39,000	15.0	A	10	380	5.0

Based on the 1958 current output from the magnesium anode beds, the calculated life for each bed is as shown in Table 5. Using 50 percent current efficiency for the anodes and 85 percent utilization, the minimum indicated life is 22 years with a present life expectancy for four of the beds in excess of 50 years. If current output increases as the system ages, the life expectancy will drop. The beds have ample capacity, lifewise, to operate at higher outputs without necessity for frequent replacement.

Maintenance

Maintenance requirements on the company's cathodic protection installation are small in comparison with the extent of the piping system. Observing the readings of the indicating voltmeters on a routine basis is the only necessary scheduled maintenance operation other than annual or semiannual detailed system checks. These checks would include performance measurements at the magnesium anode beds as well as determination of the status of cathodic protection

in stray current areas, at foreign pipeline crossings, at shorted cased crossings, and at any other points where protective potentials could be affected more rapidly with time than might be the case on the system in general.

After the first few years of operation, it might become desirable to install some additional magnesium anodes at such points as shorted cased crossings or at crossings with protected foreign lines if coating resistance on the foreign line drops to the point where there is a noticeable increase in the interference effect on the company's protective potentials. Additional pipeline added to the system might necessitate additional magnesium anode installations depending on the location, size, coating and length of the added pipe. In the event that the degree of stray current exposure at the north end of the system should become substantially worse, it might be necessary to take further corrective action in that area.

Summary

Experience with this system has indicated that it is entirely practical to cathodically protect a well-coated pipeline system in high resistivity soil with magnesium anodes. Performance is excellent and is attained with a minimum of operating and maintenance effort. Where magnesium anodes must be installed in high resistivity soil, long, slender anodes appear to be a satisfactory current source and, on this system, resulted in satisfactory distribution of protective potentials with anode beds protecting an average of approximately 45 miles of pipe per bed.

Acknowledgment

The author wishes to acknowledge the assistance of J. O. Sholar, President of South Georgia Natural Gas Company, for making available performance data on the system reported on as well as for granting permission for preparation of this paper.

References

1. H. C. Van Nouhuys. Cathodic Protection and High Resistivity Soils. *Corrosion*, 9, 448 (1953) December.
2. E. H. Thalmann. Galvanic Anodes Control Induced Voltages on Pipe Lines. *Corrosion*, 10, 367 (1954) November.

Any discussion of this article not published above will appear in the December, 1959 issue

how CORROSION is indexed

- **By Volumes Annually in December Issue**
- **In NACE Bibliographic Surveys of Corrosion**
- **In NACE Abstract Punch Card Service**
- **In 10-Year Index to CORROSION**
- **In Engineering Index**
- **In Applied Science and Technology Index**

TECHNICAL COMMITTEE ACTIVITIES

Rowe

Freedman

NEW OFFICERS ELECTED for Committee T-3A (Corrosion Inhibitors) are Chairman L. C. Rowe, senior research chemist with General Motors Corporation, and Vice Chairman A. J. Freedman, project engineer in the Corrosion Section of Standard Oil Company of Indiana, Whiting, Ind.

T-5A Committee Officers Elected

New officers recently elected for Technical Committee T-5A (Corrosion in Chemical Processes) are Chairman W. H. Burton and Vice Chairman L. W. Gleekman.

Mr. Burton is affiliated with Allied Chemical Corporation, Camden, N. J., as a materials consultant in the General Chemical Division and chairman of the general corrosion committee. He has a ME and MS from Stevens Institute and has been a NACE member since 1953.

In addition to his NACE activities, he is also a member of ASTM Committee C-3 on chemical resistant mortars and the High Alloy Steel Committee of the Welding Research Council of the Engineering Foundation.

L. W. Gleekman, new vice president for T-5A, has been with Wyandotte Chemicals of Wyandotte, Mich., since 1953 and is manager of the Materials Engineering Section in the company's research and engineering division. He also teaches metallurgy at the Detroit Institute of Technology and conducts an extension course at Wayne State University on the effects of corrosion.

Formerly he was assistant professor of chemical engineering at the University of Delaware after serving as a technical specialist in the Chemical Warfare Service during World War II. He has a BChE from Cooper Union Institute of Technology and a MS and PhD in chemical engineering from the State University of Iowa.

Interim Reports Published On Cast Iron Anodes

Second and third interim reports of Technical Committee T-2B on Anodes for Impressed Currents are reviewed in Book News of the General News section of this issue on page 94.

32 Technical Committee Meetings Are Scheduled at 1959 Region Conferences

Thirty-two technical committees will hold meetings at four region conferences scheduled in September and October. They are as follows:

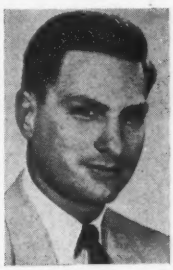
Northeast Region
October 5-8

T-2K-3 History ond Results
T-3F Corrosion by High Purity Water
T-3F-2 Inhibitors
T-3G Cathodic Protection
T-3G-1 Cathodic Protection of Hull Bottoms of Ships
T-4F-1 Materials Selection in the Water Industry

North Central Region
October 20-22

T-2L Wax-Type Pipe Coatings and Component Wrappers
T-5C-2 Corrosion by Cooling Waters, North Central Region

Riordan



Horst

RIORDAN AND HORST ARE ELECTED as officers of Committee T-2A (Galvanic Anodes). Maurice A. Riordan, partner in Rio Engineering Co., Houston, Texas, was elected chairman; R. L. Horst, Jr., Aluminum Company of America, New Kensington, Pa., is the new vice chairman.

T-5D Plastic Materials of Construction
T-6F Protective Interior Linings, Application and Methods
T-6H Glass Linings and Vitreous Enamels
T-7B North Central Region Corrosion and Co-ordinating Committee

South Central Region
October 12-15

T-1 Corrosion in Oil and Gas Well Equipment
T-1B Condensate Well Corrosion
T-1D Sour Oil Well Corrosion
T-1E Corrosion in Water Injection Systems
T-1F Metallurgy
T-1H Oil String Casing Corrosion
T-1H-3 Oil String Casing Corrosion
T-2 Pipe Line Corrosion
T-2B Anodes for Impressed Currents
T-2D Standardization of Procedures for Meausring Pipe Coating Leakage Conductance
T-2K-1 Standards
T-2K-2 Research and Development
T-6A Organic Coatings and Linings for Resistance to Chemical Corrosion
T-6B Protective Coatings for Resistance to Atmospheric Corrosion
T-6D Industrial Maintenance Painting
T-6E Protective Coatings in Petroleum Production
T-8 Refining Industry Corrosion
T-8A Chemical Cleaning

Western Region
Sept. 29-Oct. 1

T-5C-3 Corrosion By Cooling Waters Western Region
T-6J Los Angeles Area, Protective Coating Application Problems

Membership in NACE Technical Unit Committees

A question frequently asked by guests attending meetings of Technical Unit Committees is "How may I become a member of this committee?" This question is answered in the following procedure quoted from the Technical Committee Operation Manual:

1. Any member of NACE (irrespective of place or country of residence) may become a member of a Technical Unit Committee upon fulfillment of the following requirements.

2. He should apply in writing to the Chairman of the Unit in which he desires membership, stating his interest and willingness to participate in the activities of the Unit and giving his experience in the subject.

3. Approval by the Chairman of the Unit Committee of the application or by majority vote of committee members by letter ballot is necessary for appointment of an applicant to membership in a Unit Committee.

4. The Chairman of the Unit Committee will notify each applicant of his acceptance or rejection.

A directory of NACE Technical Unit Committees and Officers is published in the January, April, July and October issue of CORROSION.

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REPRESENTATIVES AROUND THE WORLD

NACE NEWS

Caliper Gives 3-D Internal Picture Of Oil Well Tubing

A tubing caliper that gives the equivalent of a three-dimensional picture of the inside of oilwell tubing was described at a meeting of Houston Section August 11. The dinner meeting, at the Houston Scientific and Technical Society Building, was attended by about 40 members and guests.

Jack Kinley, of M. M. Kinley Co., Houston told his audience that his company's device, developed out of patents issued in 1937 to his father, produced a record of greater precision and reliability than could be obtained with earlier calipers. The Kinley Microscopic Caliper has 14 feelers each of which is connected directly to one of 14 styli which records the findings of the feelers independently of the other styli.

Earlier calipers developed by his company, Mr. Kinley said, were constructed in such a way that one feeler could and often did dominate the record made by the single stylus to which all feelers were connected. This produced a record which, while satisfactory under conditions prevailing at the time, did not nearly approach the accuracy and reliability of the record made by the current improved model.

Low Pressure on Runners

One important feature of the new device, Mr. Kinley said, is the low tracking pressure employed on feelers. At standard speeds pressure is held at about 5.5 pounds; at slow speeds as little as 3.5 pounds can be used. This reduces liklihood of damage to inside of tubing by the caliper.

The record produced by the styli, a microscopic track made on a cylindrical chart measuring 8 inches by one inch diameter, is decoded in a special device by the Kinley Company. This decoder produces a photographic positive and a film negative. Both can be examined for interpretations. The company also supplies an interpretation of the caliper's findings as part of its service.

The chart will make a continuous record of up to 14,000 feet of tubing. It is possible also to make a multiple record of selected areas inside a well without removing the caliper from the tubing. In some cases a well may be calipered more than once, in which instance it is assumed that the feelers do not necessarily track and that the resulting record is additional. This permits a much more detailed picture of the tubing's condition, Mr. Kinley said.

Precise Determination Possible

It is possible to single out different kinds of corrosion damage inside the tubing. For example, Mr. Kinley said, the record will distinguish among vertical line damage running from joint to joint, indicating the effects of scraping by tools; ringworm corrosion, pits, thinning of tubing wall, out-of-round tubing and inferentially, scale buildup.

The order of accuracy is high, Mr. Kinley said, in response to a question. A comparison between a caliper survey and a micrometer check of the same tubing removed from a well showed pits were measured to .001-inch and that the measurements were accurate to .01-inch.

C. B. Tinsley, Southwestern Bell Telephone Co., section chairman, announced that the October section meeting probably will be postponed because the meeting date conflicts with that of the South Central Region meeting at Denver.

Annual Shreveport Short Course to Be September 22-23

The 8th Annual Corrosion Short Course sponsored by the Shreveport Section will be held Sept. 22-23 on the Centenary College campus. The short course is designed for oil and gas industry personnel. Registration and all meetings will be held in the Science Building.

Registration fee will be $15, which entitles registrants to lunch in the college cafeteria during the course and to the banquet.

Banquet tickets will be $5 each for persons not wishing to attend the course sessions.

Program Schedule

Tuesday, Sept. 22, Morning Sessions

Operator's Interest, M. V. Cousins, United Gas Pipe Line Co.

Basic Causes and Symptoms, H. V. Beezley, United Gas Pipe Line Co.

Methods of Control, James A. Irvin, Arkansas Louisiana Gas Co.

Cost of Control, T. M. Davis, Jr., Arkansas Fuel Oil Corp.

Tuesday, Sept. 22, Afternoon Sessions

Selection and Application of Paint, Carl Sutton, Carthage Corp.

Selection and Application of Coatings, M. J. Olive, Arkansas Fuel Oil Corp.

Maintenance of Cathodic Protection Rectifiers, W. L. Pevy, Interstate Oil Pipe Line Co.

Use of Inhibitors, J. W. Graves, United Gas Pipe Line Co.

Installation of Insulating Devices, G. S. Jones, Texas Eastern Transmission Co.

Wednesday, Sept. 23, Morning Sessions

Special Plant Problems, J. W. McCutchen, United Gas Pipe Line Co.

Special Production Problems, H. G. Byars, Atlantic Refining Co.

Special Pipeline Problems, D. A. Tefankjian, Texas Eastern Transmission Co.

Wednesday, Sept. 23, Afternoon Sessions

What Corrosion Engineers Expect of Field Men, B. M. Dearing, Texas Eastern Transmission Co.

What Field Men Expect of Corrosion Engineers, Lee P. Chapman, United Gas Pipe Line Co.

Technical Forum, D. A. Tefankjian, moderator.

•

South Central Region's 1959 Conference will be held October 12-15 at the Cosmopolitan Hotel in Denver, Colo.

Only 14 Booths Left For Corrosion Show

Only 14 booths are left for the 1960 Corrosion Show to be held March 15-17 in conjunction with the 16th Annual NACE Conference in Dallas, Texas.

Companies interested in having a display booth at the Dallas conference should contact R. W. Huff, NACE Exhibits Manager, 1061 M & M Bldg., Houston 2, Texas.

The Corrosion Show will be held in Dallas Memorial Auditorium. Technical meetings of the conference will be on the two floors above the exhibit area.

The booths are 8 feet deep and 10 feet wide with water, drainage, electricity and air connections. Booths have been arranged to give best traffic flow to as many booths as possible.

Coburn Joins U. S. Steel

S. K. Coburn, chairman of the Technical Program for the 1960 Annual Conference to be held in Dallas, Texas, is now affiliated with U. S. Steel Corporation, Monroeville, Pa. He will be associated with the Applied Research Laboratory.

Mr. Coburn formerly was with the Association of American Railroads in Chicago, Ill.

DEATHS

Hugo W. Wahlquist, NACE member and corrosion engineer with Ebasco Services Inc., died July 9. With Ebasco for the past 17 years, he was supervisor of all engineering activities involving corrosion control. He resided in Ardsley, N. Y.

Western Region News

San Francisco Bay Area Section will hold its September 8 meeting at Spenger's Fish Grotto, 1919 Fourth St., Berkeley, Cal. William W. Kurz, president of Vacu-Blast Co., Inc., Belmont, Cal., will speak on Modern Blast Cleaning for Corrosion Control.

Western Region Conference Program

A schedule of the technical program for the 1959 Western Region (Sept. 29-Oct. 1) appeared on pages 88 to 91 of the August issue of CORROSION. Headquarters for the conference will be the Bakersfield Inn, Bakersfield, Cal.

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North Central Region News

Kansas City Section held a panel discussion on corrosion problems of underground structures in urban and metropolitan areas at the May 11 meeting.

Announcement was made that 46 persons completed the corrosion short course held earlier in the year at St. Theresa College.

1959 North Central Region Conference Program

A complete program of the 1959 North Central Region Conference (Oct. 20-22 in Cleveland, Ohio) appears on pages 84 to 90. Included are schedule of events, technical program, abstracts of papers to be presented and photos and biographical sketches of authors.

Four technical committee meetings are scheduled for the North Central Region Conference, October 20-22, in Cleveland, Ohio.

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The 1959 North Central Region Conference will be held October 20-22 in Cleveland, Ohio.

Wood

Spurgeon

Southwest Ohio Section Elects 1959-60 Officers

New officers recently elected by the Southwest Ohio Section are as follows: Chairman R. L. Wood, Vice Chairman W. M. Spurgeon, Treasurer A. D. Caster and Secretary S. C. Jones.

Directors for the section are L. M. Lederer, R. B. Stephenson, H. H. Cantwell, A. F. Andres and A. D. Jenss.

Wilbur E. Hare was elected regional representative trustee effective January 1, 1960.

Joseph Bigos of U. S. Steel Corporation spoke at the May 26 section meeting on surface preparation.

South Central Region News

Shreveport Section Plans '59-60 Programs and Dates

Meeting dates and program for 1959-60 were set for the Shreveport Section at a recent meeting of the Program Planning Committee.

Each meeting will be held in the Colonial Room of the Captain Shreve Hotel with Fellowship Hour at 6, dinner at 7 and the speaker at 8.

Dates and subjects or special event for the year are given below:

October 6: Cathodic protection of pipeline coatings.
November 3: Well corrosion control.
December 1: Plant corrosion.
January 5: Economics.
February 2: Cathodic protection—design for interference.
March 1: Production equipment.
April 5: Review of the 1960 Conference in Dallas.
May 3: Cathodic protection—operation and maintenance.
June 14: Annual Barbeque.
July. No meeting scheduled.
August 2: Ladies Night.

Members of the Program Planning Committee present were Grady F. Howell, W. F. Levert, Robert P. Naremore, M. J. Olive, Ned C. Stearns, E. H. Sullivan, Frank Therrell and D. A. Tefankjian.

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Thirteen technical committee meetings are scheduled for the South Central Region Conference, October 12-15, in Denver, Colorado.

Alamo Section heard Max Schlather of United Gas Pipe Line Company speak on cathodic protection principles at the July 21 meeting. This was the second in a series of summed educational programs.

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Central Oklahoma Section will hold its next three meetings on September 14, October 5 and November 9. Meeting place will be the Tropical Cafeteria, 3023 N. W. 23rd in Oklahoma City. No meetings were held in July and August.

Meetings were held at Duncan, Enid and Ponca City last year so that members in those areas could attend at least one section meeting and to stimulate interest in NACE activities.

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NACE Certificates of Membership are available from the Central Office. Measuring 5½ x 8½ inches, the certificates cost $2 each and are signed by the association president and executive secretary.

1959 South Central Region Conference Program

A schedule of the technical symposia and the papers to be given at the 1959 South Central Region Conference (Oct. 12-15 in Denver, Colo.) is published on pages 80 to 84. Included are abstracts of the papers and photos and biographical sketches of the authors.

Well	BEFORE TREATMENT		AFTER KONTOL SQUEEZE TREATMENT	
	Tubing Failures Per Year	Iron Loss (Lbs/Day)	Tubing Failures Per Year	Iron Loss (Lbs/Day)
A	2	3.8	0	0.7
B	2	4.5	0	0.7
C	4	8.8	2	4.3
D	1	10.1	0	0.6
E	1.7	11.2	0	1.6
F	2	8.8	0	0.5
G	1.3	4.7	0	1.0
H	1.5	3.3	0	0.5
	15.5	55.4	2	9.9

See our exhibit at the International Petroleum Exposition, May 14-23, and 5th World Petroleum Congress, June 1-5.

another
TRETOLITE SERVICE
report

87% reduction
saves $52,000 annually

Squeeze Application of KONTOL*CORROSION INHIBITOR REDUCES TUBING FAILURES FROM 15.5 to 2 PER YEAR

A corrosion control program employing KONTOL substantially paid off on a Texas lease. Based on the cost of pulling wells and replacing corroded tubing, an average of $4,000 per job, the savings in one year (based on figures in table above) approximated $52,000.

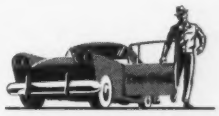
HOW KONTOL PROTECTION WAS ACHIEVED

KONTOL Corrosion Inhibitor was squeezed into the well formations at the rate of 55 gallons per well, followed by 2 quarts of TRET-O-LITE* demulsifying chemical in 15 barrels of oil, followed by oil injection sufficient to displace the liquid in the tubing and force the chemical into the formation. Injection was obtained by means of a 5 g.p.m. triplex pump and 40 g.p.m. centrifugal pump.

COST OF TREATMENT

The KONTOL squeeze treatment cost about 70 mills per barrel of produced oil and 1.9 mills per barrel of fluid produced. This resulted in a treating cost of 17 mills per barrel less than previous corrosion prevention methods.

This is just one of many cost savings stories on KONTOL Corrosion Inhibitor treatment. For more —and information on how to start a KONTOL Corrosion Control Program—ask the Man in the Red Car. Or write to . . .



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MEXICO: R. E. Power, Sierra de Mijes, No. 125, Mexico, D. F.
NETHERLANDS: F. E. C. Jenkins, Hoefbladlaan 134, The Hague
PERU: International Gas Lift Company, Apartado 71, Talara
TRINIDAD: Neal and Massy, Ltd., Port of Spain, P.O. Box 544, San Fernando

NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1959

Sept. 29-30, Oct. 1—Western Region Conference. Bakersfield Inn, Bakersfield, Cal.

Oct. 1-2—Southeast Region Conference. Jacksonville, Florida, Robert Meyer Hotel.

Oct. 5-8—Northeast Region Conference. Lord Baltimore Hotel, Baltimore, Md.

Oct. 12-15—South Central Region Conference. Denver, Colo. Cosmopolitan Hotel.

Oct. 20-22—North Central Region Conference, Cleveland, Statler Hilton Hotel.

1960

February—Canadian Region Western Division. Vancouver.

March 14-18—16th Annual Conference and 1960 Corrosion Show. Dallas, Texas, Memorial Auditorium.

Oct. 11-14—Northeast Region Conference. Prichard Hotel, Huntington, W. Va.

Oct. 19-20—North Central Region Conference. Schroeder Hotel, Milwaukee.

Oct. 25-28—South Central Region Conference, Mayo Hotel, Tulsa.

1961

March 13-17—17th Annual Conference and 1961 Corrosion Show, Buffalo, N. Y., Hotel Statler.

Oct. 9-11—North Central Region Conference, St. Louis, Chase Park Plaza Hotel.

Oct. 24-27—South Central Region Conference, Houston, Shamrock Hotel.

Oct. 30-Nov. 2—Northeast Region Conference, New York City, Hotel Statler.

1962

March 18-22—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 16-19—South Central Region Conference, Hilton Hotel, San Antonio, Texas.

SHORT COURSES

1959

September 22-23—9th Annual Shreveport Section Short Course. Centenary College.

November 16-20—4th Annual General Florida Conference 1959 Corrosion Short Course. Key Biscayne Hotel, Miami.

December 7-11—University of Illinois Corrosion Control Short Course. Urbana Campus.

1960

April 27-29—Portland Section Corrosion Control Short Course.

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226,800 copies of 25 NACE Technical Committee Reports were distributed in 1957. In 1958, 210,300 copies of 12 NACE Technical Committee Reports were distributed.

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NACE Certificates of Membership are available from the Central Office. Measuring 5½ x 8½ inches, the certificates cost $2 each and are signed by the association president and executive secretary.

Southeast Region News

'59 Florida Short Course Dates Are Set Nov. 16-20

Fifteen speakers have been set to participate in the 4th Annual General Florida Conference 1959 Corrosion Short Course to be held November 16-20 at the Key Biscayne Hotel, Miami. Speakers on eight additional topics will be determined later.

Speakers who will participate in the short course are the following: J. A. Lehman, lectro Rust-Proofing Co., G. K. Volgelsand, Gates Engineering Co., Robert A. Fergusson, Rust-o-Leum Co., V. W. Ginsler, Rust-o-Leum Co., W. R. Ahrberg, Rust-o-Leum Co., Harry R. Aschan, Goodall Electric Mfg. Co., Ken G. Compton, Bell Telephone Laboratories, A. H. Henning, General Tire and Rubber Co., B. Husock, Harco Corp., Paul Kurek, Pan American World Airways, Wilson Lynes, Revere Copper & Brass Co., T. P. May, International Nickel Co., Marshal E. Parker, consulting engineer, Henry F. Payne, University of Florida and N. T. Shideler, Pittsburgh Coke & Chemical Co.

Four moderators for roundtable discussions also have been chosen: J. B. Prime, Florida Power & Light Co., Sigmund Miller, University of Florida, E. J. Tilton, Florida Power Light Co., and H. T. Rudolph, Atlantic Coatings Co.

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News intended for publication in CORROSION should be in Houston not later than the 10th of the month preceding month of publication.

SECTION CALENDAR

September

4 Birmingham Section.
8 San Francisco Bay Area Section.
12 Corpus Christi Section. Annual Barbeque.
14 Central Oklahoma Section. Tropical Cafeteria, Oklahoma City.
15 Chicago Section. Chicago Engineers Club.
15 San Joaquin Section.
16 Los Angeles Section.
22 East Texas Section. Longview Hotel in Longview.
22 Baltimore-Washington Section. An Approach to Protective Coating Engineering, by Austin K. Long.
24 Edmonton Section.
24 Teche Section. Petroleum Club.
28 Atlanta Section.

October

5 Central Oklahoma Section. Tropical Cafeteria, Oklahoma City.
6 Shreveport Section. Captain Shreve Hotel. Cathodic Protection of Pipeline Coatings.
13 San Francisco Bay Area Section.
20 Chicago Section. Chicago Engineers Club.
22 Teche Section. Petroleum Club.
22 Edmonton Section. Corona Hotel.
23 Philadelphia Section.
27 East Texas Section. Longview Hotel in Longview.

Southeast Region Conference Program

Abstracts of papers to be presented during the 1959 Southeach Region Conference (Oct. 1-2 at the Robert Meyer Hotel, Jacksonville, Fla.) were published on page 87 of the August issue of CORROSION.

Northeast Region News

Oct. 6 Conference Banquet To Have National Speakers

Two nationally known speakers will be featured at the Northeast Region Conference Banquet to be held at the Lord Baltimore Hotel in Baltimore, Md., on October 6. The conference will be held October 5-8.

Theodore R. McKeldin, former governor of Maryland, will be toastmaster and speak briefly on Maryland.

Dr. R. Carson Dalzell, assistant to the director of reactor development of the Atomic Energy Commission, will discuss corrosion problems of nuclear reactors.

His discussion will consider the new environmental factors which corrosion engineers confront in nuclear reactors. Even the definition of corrosion failure is modified in this environment. The economics of combatting corrosion are fantastic in comparison with conventional situations.

Dr. Dalzell has a BE from Johns Hopkins University, a MS and ScD in metallurgy from Harvard University.

Before joining the AEC staff in 1940, he was engaged in applied research, development engineering, application engineering, plant control and general management in the non-ferrous metals industry.

He joined the staff of the Atomic Energy Commission to plan and administer the general materials research and development program of the Division of Reactor Development. Appointed chief of the Engineering Development Branch in 1956, he was placed in charge of all general development work.

His current responsibilities are for technical coordination of military and maritime reactor programs.

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Three technical committee meetings are scheduled for the Northeast Region Conference to be held October 5-8 at the Lord Baltimore Hotel, Baltimore, Md.

Northeast Region Conference Program

A complete schedule of events and the technical program for the 1959 Northeast Region Conference (Oct. 5-8) was published on pages 72 to 86 of the August issue of CORROSION. The conference will be held at the Lord Baltimore Hotel in Baltimore, Md.

COREXIT
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COREXIT saves you money. It prolongs the life of your sub-surface equipment, reduces the number of well-pulling jobs and prevents loss in production. Savings up to $1,000 a year per well are not unusual.

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COREXIT is an organic, adsorptive-type corrosion inhibitor. It is available in many different formulas to meet the needs of every producer. It is non-toxic and easy to handle. It has no objectionable odor.

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Tulsa, Oklahoma

in Illinois, Indiana and Kentucky—

T. E. Bennett Chemical Company
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DOW | MAGNESIUM

$175 TO $500 PROTECTS WELL CASINGS IN HUGOTON FIELD

Galvomag magnesium anodes can prevent corrosion in gas well casings for a decade or more . . . without an external power source.

In 1954, a survey of the 6,000 odd wells in the Hugoton Gas Field revealed 56 leaks. Since most of the wells were comparatively new (two-thirds were less than five years old), this was a serious problem. Projecting the rate of leak increase showed there would be over 300 leaks by 1960.

The cost of repairing these production wasting leaks usually ran between $10,000 and $40,000, using liners or the cement squeeze method. Several Hugoton producers decided to take immediate preventative action. After extensive field tests were made, it appeared that sulfate-reducing bacteria was the villain. These microorganisms convert the sulfates into hydrogen sulphide, which in turn attacks the casings. A Dow mag-

nesium anode distributor was asked to make an analysis of the situation and recommend a practical solution.

In determining the most practical type of corrosion protection, two factors had to be considered. First, the wells were situated a mile apart and few electric power lines were available. This meant a considerable expense if cathodic equipment requiring a power source were used. Second, to what depth would protection be possible? In some soil conditions, cathodic protection cannot be used at all. In the Williston Basin, for example, a massive layer of salt above the corroding formation blocks electrical currents from reaching this portion of the casing. Fortunately, the Hugoton field was free and clear of such obstructions.

By running potential-drop tests in casings throughout the field, it was found that a current of from 0.5 to 2.5 amperes would provide ample protection to total depth. The installation of Galvomag® magnesium anodes was recommended as the best solution, from the standpoint of economy, as well as ease of installation. Also, as magnesium anodes do not set up "stray" currents in the soil, there was no danger of interference with foreign structures.

MAGNESIUM ANODES in a wide range of sizes and shapes provide flexibility to allow the most efficient design in many different types of installations. Galvomag anodes (shown above) have 25% more throwing power than ordinary magnesium anodes . . . are used extensively in the Hugoton Field.

DOW DISTRIBUTORS provide experienced technical services on corrosion problems. Field tests of soil conditions and analyses of the requirements of individual wells can result in substantial savings in installation and anode costs.

Three to eighteen anodes were used per well, at a total cost of from $150 to $500 per installation. A maximum of seven were used in each bed, about 85-100 feet away from the casing. Each well was examined individually to determine the most efficient installation. Factors such as variation in soil resistance, well-to-earth resistance and potential, and current requirements were taken into full account in selecting the number and arrangement of anodes to be used for each well. The installations were designed for a ten year life but they may last 15 to 18 years because of polarization of the well casings.

Since 1954, over 800 wells in the Hugoton Gas Field have been cathodically protected with magnesium anodes. Casing leaks due to external corrosion are no longer a problem on these wells.

The Dow magnesium anode distributors listed below are ready to help you get the most for your corrosion protection dollar. Contact one of them next time you have a corrosion problem involving well casings, pipelines, storage tanks or other equipment.

AU-9

CALL THE DISTRIBUTOR NEAREST YOU:

CATHODIC PROTECTION SERVICE, Houston, Texas
CORROSION SERVICES, INC., Tulsa, Oklahoma
ELECTRO RUST-PROOFING CORP. (Service Division), Belleville, N. J.
ETS-HOKIN & GALVAN, San Francisco, Calif.
THE HARCO CORP., Cleveland, Ohio
INTERPROVINCIAL CORROSION CONTROL COMPANY, Burlington, Ontario
ROYSTON LABORATORIES, INC., Blawnox, Penna.
STUART STEEL PROTECTION CORP., Plainfield, N. J.
THE VANODE CO., Pasadena, Calif.

THE DOW CHEMICAL COMPANY · MIDLAND, MICHIGAN

Program Schedule, South Central Region Conference

Technical Program Includes 30 Papers For Denver Meeting

Approximately 30 technical papers on a variety of corrosion control subjects will be presented in six symposia and a series of educational lectures at the 1959 South Central Region Conference to be held October 12-15 in Denver, Colo.

Headquarters for the conference will be the Cosmopolitan Hotel; room reservations are being made at the Brown Palace Hotel also.

A listing of the papers scheduled to date for the six symposia are given below.

Seventeen technical committees have scheduled meetings during the conference. Meeting times and places for these meetings will be given in the printed program.

Social Events

A dinner dance will be held Wednesday, Oct. 14, from 7 to 9 pm in the Silver Glade Room of the Cosmopolitan Hotel. Entertainment for the dinner is being planned.

Fellowship Hour is scheduled for 6:30 pm, Tuesday, Oct. 13, in the New Ballroom of the Brown Palace Hotel. Special entertainment is planned.

Ladies Program Planned

Feature of the Ladies Program will be a trip through the new Air Force Academy near Colorado Springs with luncheon at the famous Broadmoor Hotel.

A fashion show and other activities also are planned for the ladies.

Special Technical Plant Visits

Two visits to technical establishments are scheduled. One is the Bureau of Reclamation Engineering Laboratories; the other is Ohio Oil Company's Research Center, considered one of the most modern laboratories in this country.

Technical Program

A schedule of the symposia with the papers to be given is listed below.

Names of the chairmen and co-chairmen of the symposia were given in the August issue of CORROSION.

Pipeline Corrosion

Wednesday, October 14

Chairman Frank B. Burns, General Asphalts, Inc., Wynnewood, Okla., Co-Chairman M. J. Olive, Arkansas Fuel Oil Corp., Shreveport, La.

Management's Viewpoint of Corrosion Protection of Pipeline Systems, by Harry K. Phipps, Mobile Oil Co., Wichita, Kansas.

Important Qualities of Heavy-Type Mastic Pipe Coatings, by Lyle R. Sheppard, Shell Pipeline Corp., Houston, Texas.

Organization and Operation of Corrosion Field Test Forces, by Lance F. Heverly, Trans-Canada Pipeline, Ltd., Toronto, Ontario, Canada.

Packaged Cathodic Protection of the 1600-Mile Tape Coated Pipe Line to Florida, by E. P. Doremus and Ralph B. Pass, Cathodic Protection Service, Houston, Texas.

Reservations and Registration

Pre-registration blanks have been mailed to NACE members. Room reservation forms were included in this mailing.

Reservations for sleeping rooms and suites at both hotels should be sent to Bryan Patterson, conference housing committee chairman, Hill Hubbell and Co., 2220 19th St., Denver, Colo.

Corporate member company requests for rooms will be honored upon receipt. Other requests are being assigned in order received until all available suites and rooms are assigned.

Refining and Chemical Process Industries

Wednesday, October 14

Chairman E. L. Haile, Monsanto Chemical Co., Texas City, Texas, Co-Chairman L. M. Rogers, Union Carbide Chemicals Co., Texas City, Texas.

Anodic Passivation Studies, by J. D. Sudbury, O. L. Riggs and D. A. Shock, Continental Oil Co., Ponca City, Okla.

Anodic Control of Corrosion in a Sulfonation Plant, by O. L. Riggs, Merle Hutchinson and N. L. Conger.

Application of Anodic Corrosion Control in the Chemical Industry, by D. A. Shock, O. L. Riggs and J. D. Sudbury.

Laboratory and Field Use of the Recording Corrosometer, by E. C. Weingartner, Humble Oil Co., Baytown, Texas.

Cast Stainless Steels for High Temperature Oil Refining and Chemical Plant Service, by A. F. Gross, Ohio Steel Foundry, Springfield, Ohio.

Oil and Gas Production

Thursday, October 15

W. C. Koger, Cities Service Oil Co., Bartlesville, Okla., Co-Chairman J. A. Caldwell, Humble Oil & Refining Co., Houston Texas.

Baked-On Plastic Coatings for Tubular Goods, by Glenn R. Roberson, Standard Oil Company of Texas, Houston, Texas.

Corrosion Inhibitor Evaluation at Elevated Temperatures, by V. W. Maxwell, Sun Oil Co., Beaumont, Texas.

Effect of pH on Oxygen Corrosion at Elevated Pressures, by O. L. Riggs, J. D. Sudbury and D. A. Shock, Continental Oil Co., Ponca City, Okla.

Effect of pH on Aerobic Corrosion Fatigue, by F. J. Radd and Hugh Crowder.

Utilities and Communication Industries

Thursday, October 15

Glenn W. Beesley, Dallas Power & Light Co., Dallas, Texas, Co-Chairman T. J. Maitland, American Telephone & Telegraph Co., New York, N. Y.

A study of Fouling and Corrosion in Condenser Tubes, by R. A. McAllister, Lamar State College of Technology, Lamar, Texas, and Mitchell Hollier, Gulf States Utilities, Beaumont, Texas.

Things New or Unusual in Mitigation of Corrosion in the Utilities Field, by E. H. Thalmann, Ebasco Services, Inc.

Some Factors in Design of Cathodic Protection Systems for Communication Cables, by A. F. Minor, American Telephone and Telegraph Co., New York, N. Y., and V. B. Pike, Bell Telephone Laboratories, Murray Hill, N. J.

Grounding and Insulating Practices of a Gas Distribution System, by Harry R. Brough, Mountain Fuel & Supply Co., Salt Lake City, Utah.

High Temperature Corrosion

Thursday, October 15

J. J. Moran, International Nickel Co., Inc., New York, N. Y., Co-Chairman J. H. DeVan, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Problems of High Temperature Corrosion in Nuclear Reactors, by W. O. Harms, University of Tennessee.

High Temperature Corrosion Problems in Vehicles for High-Speed Flight, by C. C. Clark, International Nickel Co., Inc.

Tubular Products in Elevated Temperature Corrosion Environments, by Thomas M. Krebs, Babcock and Wilcox Co., Beaver Falls, Pa.

Fresh Water Corrosion

Thursday, October 15

J. M. Brooke, Phillips Petroleum Co., Sweeny, Texas, Co-Chairman Roy V. Comeaux, Humble Oil & Refining Co., Baytown, Texas.

Reclamation's Use of Protective Coatings for Submerged and Buried Metal Work, by Paul W. Lewis and J. L. Kiewit, Bureau of Reclamation, Denver, Colo.

Some Notes on Corrosion Mechanisms of Ferrous Metals in Aerated Aqueous Solutions, by M. C. Forbes, Larry Twiford and R. O. Johnson, Aquatrol, Inc., Houston, Texas.

Wood Maintenance for Cooling Towers, by James L. Willa, Cooling Tower Institute, Houston, Texas.

Educational Lectures

Three educational lectures have been scheduled for Tuesday and Thursday afternoons, October 13 and 15:

A Demonstration on Electrochemical Corrosion Reactions, by George G. Cox, consulting engineer.

Corrosion Testing Instruments, by M. C. Miller.

Bacterial Activity at Bottom of Back-Filled Pipeline Ditch, by John O. Harris, Kansas State College.

South Central Conference ABSTRACTS

Pipeline Corrosion Symposium

Characteristics of Asphalt Mastic Coatings, by Lyle R. Sheppard, Shell Pipe Line Corp., Houston, Texas.

Describes characteristics of asphalt mastic which can affect its performance for corrosion protection and weighting agent. Results are derived from coating project on 16-inch line. Every 50th coated joint was tested at the coating plant shortly after application for blunt needle penetration. Daily samples of binder and finished mastic from the pipe were tested in the laboratory for binder softening point and penetration, mastic proportioning, bulk density, adhesion, cohesion, apparent voids and temperature characteristics.

Packaged Cathodic Protection of the 1600-Mile Tape Coated Pipe Line to Florida, by E. P. Doremus and Ralph B. Pass, Cathodic Protection Service, Houston, Texas.

Discusses unusual problems enuountered in design and installation of a cathodic protection system for the 1600-mile big inch pipe line system from Baton Rouge, La., to Miami, Fla. Presents coating resistance data on this first major all polyethylene tape coated pipe line taken immediately after laying and after application of cathodic protection.

(Continued on Page 82)

Authors of Papers, South Central Region Conference

Cox

Crowder

Doremus

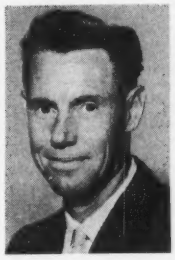
Eastham

Gross

Harms

Heverly

Hollier


Hutchison

Kiewit

Lewis

Maxwell

McAllister

Miller

Minor

Pass

Phipps

Pike

Radd

Riggs

Roberson

Sheppard

Shock

Sudbury

Thalmann

Willa

Wolfe

South Central Conference BIOGRAPHIES

G. C. COX, retired Army colonel, is a consulting engineer on corrosion control processes. He has a BS and MS in electrical engineering from North Carolina State College. His Army career included corrosion control projects in Europe during World War II.

L. H. CROWDER is affiliated with Continental Oil Company's research organization. He has a BS from Oklahoma State University. His work has involved metallography.

(Continued on Page 82)

South Central Conference BIOGRAPHIES

(Continued From Page 81)

E. P. DOREMUS is president of Cathodic Protection Service, Houston, Texas. He has a BS in chemical engineering from Southwest Louisiana Institute and a MS from Louisiana State University. Formerly he was with Shell Oil Company. He is a member of NACE and also vice president of Grebe & Doremus Process Co.

DONALD H. EASTHAM has a BS in chemical engineering from Lamar State College of Technology.

A. F. GROSS has been associated with Ohio Steel Foundry Company for 16 years. As chief metallurgist, his work is primarily research and development. He has a BS in mathematics from Colorado State College and has written several papers on foundry metallurgy and melting practice.

W. O. HARMS is associate professor of metallurgical engineering at the University of Tennessee and consultant for the Metallurgy Division of the Oak Ridge National Laboratories.

L. F. HEVERLY is corrosion engineer with Trans-Canada Pipe Lines, Ltd., Toronto, Ontario. He has been in corrosion control work since 1941. He has a BS in electrical engineering from Pennsylvania State College. He has been active in NACE since 1946.

MITCHELL HOLLIER is affiliated with Gulf States Utilities Co., Beaumont, Texas. His duties include studies of corrosion causes and methods of prevention, boiler water treatment and analysis of boiler and cooling water. He has a BS in chemistry from Southwestern Louisiana Institute.

MERLE HUTCHISON has been associated with Continental Oil Company since 1948. He has worked in research of core analysis and corrosion involving all phases of petroleum operations. Currently he is working on chemical and electrochemical studies of corrosion mechanisms and prevention.

J. L. KIEWIT is an engineer with the Bureau of Reclamation, Denver, Colo. He has been with the Protective Coatings Laboratory Section since 1953, supervising field inspection of protective coating applications and conducting laboratory investigations of commercial coatings. He has a BS in chemical engineering from the University of Nebraska.

T. M. KREBS is metallurgist supervisor of research at Babcock & Wilcox Co., Tubular Products Division, Beaver Falls, Pa. He is a member of NACE, API and ASM. He has a BS in metallurgy from Pennsylvania State University.

PAUL W. LEWIS is head of the Protective Coatings Laboratory Section, Bureau of Reclamation Laboratories, Denver, Colo. A NACE member, he was 1958 chairman of the Rocky Mountain Section and is a member of Technical Committees T-6B and T-6F.

R. A. McALLISTER is professor of chemical engineering at Lamar State College of Technology and a consultant for Gulf States Utilities Co., Beaumont, Texas. He has a BS in chemical engineering from North Carolina State College, MS from the University of Wisconsin and MIT and a PhD from Georgia Institute of Technology.

VICTOR W. MAXWELL is in the production laboratory of Sun Oil Co., Beaumont, Texas. His work involves problems of oil and gas condensate well corrosion. He is a member of NACE and has a BS and MS in chemistry from Baylor University.

A. F. MINOR is an engineer with American Telephone and Telegraph Co., New York City. He has specialized in corrosion studies related to underground and buried communication cables since 1940. He has been active in NACE since 1949. He is a member of several technical committees and has been vice chairman of the Metropolitan New York Section and chairman of regional committee.

RALPH B. PASS is a corrosion engineer for Cathodic Protection Service's New Orleans branch office. He has a BS in civil engineering, has been in corrosion engineering work since 1952 and is a member of NACE and ASCE.

HARRY K. PHIPPS is manager of Mobil Oil Company's central pipe lines division in Wichita, Kansas. A charter member of NACE, he has been employed by Socony Mobil Oil Company, Inc., for 38 years. He is also a member of API.

F. J. RADD, affiliated with Continental Oil Company since 1952, is involved in study of the low temperature behavior of metals, their oxidation responses and corrosion fatigue properties. He has a BS in metallurgy from University of Missouri and ScD from MIT.

O. L. RIGGS, JR., has been a member of Continental Oil Company's research department since 1952 and has worked in the field of corrosion chemistry. He is in charge of the Corrosion Group. He has a BS in chemistry from Eastern Nazarene College.

MAURICE A. RIORDAN is a partner in Rio Engineering Co., Houston, Texas. He has been active in corrosion work and cathodic protection since 1946. He has a BS in metallurgical engineering from Rensselaer Polytechnic Institute.

GLENN R. ROBERSON is a chemical engineer with Standard Oil Company of Texas, Houston. His work is in corrosion control in oil and gas production and waterflooding. He has a BS in chemical engineering from Rice Institute and is a member of NACE.

LYLE R. SHEPPARD is senior engineer in corrosion research with Shell Pipe Line Corp., Houston, Texas. He has a BS and MS from the University of Houston. A charter member of NACE, he is on several technical committees and has been in pipe line corrosion control work since 1932.

D. A. SHOCK, research group leader at Continental Oil Company's research laboratory, Ponca City, Okla., has been active in NACE work for several years. He has a BS from Colorado College and a MS in chemistry from the University of Texas.

J. D. SUDBURY is a member of Continental Oil Company's research and development staff, serving as supervising research chemist of the Central Research Division. He has a PhD in physical chemistry from the University of Texas.

E. H. THALMANN is electrical engineer for Ebasco Services, Inc., New York, N. Y. He has a BS in electrical engineering from Cooper Union Institute of Technology and is chairman of NACE's Technical Committee T3-D. at Ebasco, he is responsible for corrosion control projects, electric power plants, underground cable systems, underground structures and general corrosion studies and investigations.

JAMES L. WILLA is manager of the Cooling Tower Institute, Houston, Texas. He has a BA and a BS in Chemical Engineering from Rice Institute. He has been with the institute since 1951.

L. H. WOLFE is affiliated with Continental Oil Company doing corrosion fatigue work. He has a BS in mathematics and physics from Northwestern State College.

South Central Conference ABSTRACTS

(Continued From Page 80)

Organization and Operation of Corrosion Field Forces, by L. F. Heverly, Trans-Canada Pipe Lines Ltd., Toronto, Ontario.
Discusses organization of operating department of a pipeline company showing channels for work plans and instruction through division superintendents to field personnel. Also discusses organization of the corrosion section, giving duties and work functions of corrosion personnel.

Refining and Chemical Process Industries Symposium

Cast Stainless Steels for High Temperature Oil Refining and Chemical Plant Service, by A. F. Gross, Ohio Steel Foundry, Springfield, Ohio.
Discusses the metallurgical reasons for differences between cast and wrought materials. Presents examples of service failures resulting from failure to recognize these differences. Effect of temperature on usual corrosion grades is presented as a material selection chart. Also covers oxidation resistance, sigma formation, carbide precipitation and embrittling.

Oil and Gas Production Symposium

Baked-On Plastic Coatings for Tubular Goods, by G. R. Roberson, Standard Oil Company of Texas, Houston, Texas.
Reports results of testing 33 coating arrangements on plastic coated tubing. Phenolics are separated into four classes; epoxy modified phenolics into six classes. Discusses problems connected with application of coatings for high pressure, high temperature wells and presents economic reasons for use of plastic coated tubing.

Corrosion Inhibitor Evaluation at Elevated Temperatures, by V. M. Maxwell, Sun Oil Co., Beaumont, Texas.
Evaluation of commercially available organic corrosion inhibitors at elevated temperatures is presented. All these were designed for down-hole treatment of producing oil and gas wells. These evaluations are compared to evaluations of same inhibitors at room temperature. Details of test are given: apparatus, material used and test method. Results are given in tabular form and block graph to show average percent protection obtained for each inhibitor at the temperatures tested.

Effect of pH on Oxygen Corrosion at Elevated Pressures, by O. L. Riggs, Jr., J. D. Sudbury and Merle Hutchison, Continental Oil Co., Ponca City, Okla.
Presents summary study of oxygen corrosion of mild steel in brines. Corrosion rates were determined for oxygen pressures from atmospheric to 515 psia and over pH range from 1 to 13.5. Shows that corrosion rates generally increase with increased oxygen pressure and decreasing pH. An unusual filamentary type corrosion product develops and grows in the 300 to 500 psi oxygen pressure range in pH 1 system. Identification and proposed mechanism of growth is given.

Effect of pH on Aerobic Corrosion Fatigue of Steel, by F. J. Radd, L. H. Wolfe and L. H. Crowder, Continental Oil Co.
This experimental fatigue testing was conducted on AISI 1036 steel in pH range 7 to 14 and higher, a 3 percent Na Cl brine used as the aerobic electrolyte. Data are interpreted and projected to include theoretical assessment of results, both as to mathematics of the fatigue curves and to chemical behavior of steel surfaces. The study is applicable to common steels used in any aerobic fatigue environments.

Utilities and Communication Industries Symposium

A Study of Fouling and Corrosion in Condenser Tubes, by R. A. McAllister, Lamar State College of Technology, Beaumont, Texas Donald H. Eastham, Port Neches, Texas, and Mitchell Hollier, Gulf States Utilities, Beaumont, Texas.
Tests reported give quantitative data on fouling and corrosion rates in 17 to 20-foot condenser tubes under simulated operating conditions using Neches River water as cooling medium inside the tubes. Alloys tested were 90-10 cupro-nickel, aluminum-brass, Alclad aluminum, Admiralty brass silicon-coated Admiralty, phenolic coated Admiralty, three stainless steels and alloy 77. Effect of weekly caustic addition, continuous cathodic protection, river water velocity and preheating the cooling water was determined. Other variables measured were river water pH, chloride ion content, chemical oxygen demand and dissolved oxygen. Effect of these variables are discussed qualitatively.

Some Factors in Design of Cathodic Protection Systems for Communication Cables, by A. F. Minor, American Telephone and Telegraph Co., New York, N.Y., and V. B. Pike, Bell Telephone Laboratories, Inc., Murray Hill, N.J.
Discusses cathodic protection systems used for protection of underground lead covered telephone cables. Includes measurement of cable-to-earth voltage, amount of current required, right-of-way, interference on neighboring structures and economics of cathodic protection systems.

Things New or Unusual in Mitigation of Corrosion in the Utilities Field, by E. H. Thalmann, Ebasco Services, Inc., New York, N. Y.
Discusses use of distributed high silicon cast-iron anodes for corrosion protection of an underground lead covered cable distribution system. Electrolytic zinc cells for use on pipe-type cables and for control of induced voltage on pipelines are described. Also discusses use of well-type ground beds for cathodic protection of buried metallic structures at generation stations and methods of protecting silicon rectifiers from damage caused by surges. Use of concrete as coating on steel structures in shielded areas of cathodically protected complex systems is described. Also explains use of zinc paint for protection of steel in certain situations.

Fresh Water Corrosion Symposium

Reclamation's Use of Protective Coatings for Submerged and Buried Metal Work, by P. W. Lewis and J. L. Kiewit, Bureau of Reclamation, Denver, Colo.
Discusses Bureau of Reclamation's use of protective coatings in variable fresh waters of the 17 western states to control corrosion of metal work. Standard specification materials are used. Evaluation and special tests of new products keep the Bureau abreast of new technology in corrosion control. Special emphasis is given to proper coating application under field conditions and to inspection of all stages of work.

Wood Maintenance for Water Cooling Towers, by James L. Willa, Cooling Tower Institute, Houston, Texas.
Gives report on 8-year study of wood maintenance

(Continued on Page 90)

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SCOTCHRAP

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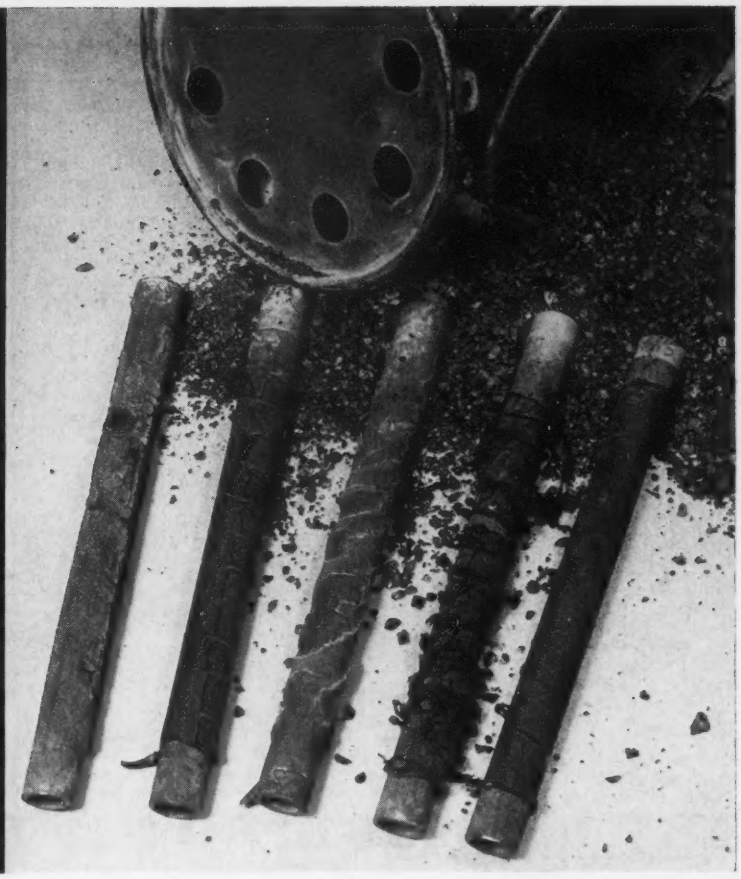
PIPE PROTECTION

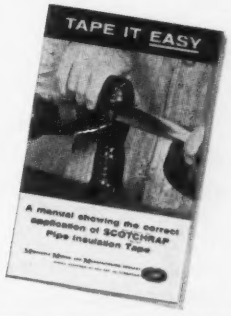
Tapes are TOUGHER!

Proved by 200-hour torture test!



Each of the five lengths of pipe shown was covered with a different protective coating—both tapes and mill coatings. They were then fastened in a barrel containing abrasive tumbling chips and continually tumbled for 200 hours. This unretouched photo shows the results: only the "SCOTCHRAP" Pipe Protection Tape, far right, survived intact!

This controlled test was designed to measure the resistances of various coatings to backfilling and soil stresses. It clearly demonstrates the superior abrasion and puncture resistance and excellent bond strength you get *only* with "SCOTCHRAP"—the toughest polyvinyl chloride plastic tape. These properties are so superior that with normal care, no protective overwrap is needed. Add the excellent electric properties, and you have the reasons why we believe "SCOTCHRAP" is the best total coating buy you can make.



SEND FOR FREE MANUAL!
New "Tape it Easy" booklet gives application methods, useful specifications, for "SCOTCHRAP" Pipe Protection Products. Write 3M Co., St. Paul 6, Minn., Dept. EAM-99.

FOR **MAXIMUM ABRASION RESISTANCE . . .**
EXCELLENT PUNCTURE RESISTANCE . . .
MAXIMUM RESISTANCE TO SOIL STRESS . . .

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North Central Region Conference, Program Schedule

Complete Schedule Is Given of 3-Day Technical Program

High temperature corrosion problems, inhibitors, coatings, plastics and other miscellaneous subjects of interest to corrosion engineers and persons in corrosion control work will be discussed during the 1959 North Central Region Conference to be held October 20-22 at the Statler-Hilton Hotel in Cleveland, Ohio.

Technical papers to be given are listed below under symposia headings with the dates and times for each symposium.

Technical Committee Meetings

Eight technical committees will meet during the conference. Dates and meeting times for these are as follows:

T-2L (Wax-Type Pipe Coatings and Component Wrappers), Wednesday, Oct. 21, 9 am.

T-5D (Plastic Materials of Construction), Wednesday, Oct. 21, 9 am.

T-6H (Glass Linings and Vitreous Enamels), Tuesday, Oct. 20, 2 pm.

T-3F-2 (Inhibitors), Thursday, Oct. 22, 2 pm.

T-5C-2 (Corrosion by Cooling Waters —North Central Region), Thursday, Oct. 22, 9 am.

T-6F (Protective Interior Linings, Application and Methods), Oct. 20, 2 p.m.

T-7 (Corrosion Coordinating Committee), Tuesday, Oct. 20, 9 am.

T-7B (North Central Region Corrosion Coordinating Committee), Thursday, Oct. 22, 9 am.

Protective Coatings—Part 1

Tuesday, Oct. 20, 9:30 am - 12 noon

Chairman S. W. McIllrath, Diamond Alkali Co., Cleveland, Ohio.

Protective Coating Testing by the Manufacturer, by Garmond G. Shurr, Sherwin Williams, Co., Chicago, Ill.

Protective Coating Testing by the User, by Kenneth Tator, Kenneth Tator Associates, Caraopolis, Pa.

Drying Oil Coatings for Corrosion Protection, by Everett Hood, Glidden Co., Cleveland, Ohio.

Materials of Design—Metals

Tuesday, Oct. 20, 9:30 am to 12 noon

Chairman A. M. Montgomery, Aluminum Company of America, Cleveland, Ohio.

Good Design Promotes Good Services, by E. D. Verink, Jr., Aluminum Company of America.

Metals for Combating Corrosion in the Process Industries, by F. L. Whitney, Jr., Monsanto Chemical Co.

Polarization and Galvanic Corrosion, by Thomas P. May, International Nickel Co., Inc., Kure Beach Harbor, N. C.

Cathodic Protection, Part 1

Tuesday, Oct. 20, 2 - 4:30 pm

Chairman Bernard Husock, Harco Corp., Cleveland, Ohio.

Cathodic Protection for Hydraulic Structures for Fresh Water, by John Rohwedder, Corporation of Engineers.

Cathodic Protection Program for Industrial Water Storage Tanks, by H. M. Patton, Brown Shoe Co., St. Louis, Mo.

Materials of Design—Plastics, Part 1

Tuesday, Oct. 20, 2 - 4:30 pm

Chairman R. B. King, Heil Process Equipment Corp., Cleveland, Ohio.

Use of Polyester and Epoxy Resins for Emergency Repairs, by Walter A. Szymanski, Hooker Chemical Co.

Design Considerations for Applying Reinforced Plastics to Corrosive Environments in the Process Industries, by Fred W. Arndt, Heil Process Equipment Corp., Cleveland, Ohio.

Plastic Materials for Construction of Corrosive Environments: Their Testing and Evaluation, by Otto Fenner, Monsanto Chemical Co., St. Louis, Mo.

Chemical Treatment

Wednesday, Oct. 21, 9:30 am - 12 noon

Chairman Fred B. Hamel, Standard Oil Company, Cleveland, Ohio.

Four Years' Experience in Treating a Cooling Water System for Corrosion Control, by W. A. Hess, Standard Oil Company of Ohio, Cleveland, Ohio.

British-American Experience With Inhibitors in Low Temperature Service, by H. G. Bennett, British-American Oil Co.

Thirty Years' Experience With Silicates as Corrosion Inhibitors in Water Systems, by H. L. Shuldener and S. Sussman, Water Service Laboratories, Inc., New York, N. Y.

Protective Coatings, Part 2

Wednesday, Oct. 21, 9:30 am - 12 noon

Chairman Paul J. Gegner, Columbia-Southern Chemical Co., Barberton, Ohio.

Epoxy Resin Protective Coatings, by N. A. Mason, Pittsburgh Plate Glass Co., Pittsburgh, Pa.

Paper to be scheduled by C. G. Munger, Amercoat Corp., South Gate, Cal.

Chemically Modified Coal Tar Coatings, by Francis R. Charlton, Koppers Co., Inc., Pittsburgh, Pa.

Shop Coating of Structural Steel, by John D. Keane, Steel Structures Painting Corp., Pittsburgh, Pa.

Protective Coatings, Part 3

Thursday, Oct. 22, 9:30 am - 12 noon

Chairmen S. W. McIllrath and Paul J. Gegner.

Sprayed Metal as a Base for Protective Coatings, by Eugene C. Warner, Akron Sandblast & Metallizing Co., Barberton, Ohio.

New Developments in Protective Linings, by Wallace P. Cathcart, Tank Lining Council, Pittsburgh, Pa.

Specialty Coatings for Corrosion Protection, by R. A. Garling, U. S. Stoneware Co., Stow, Ohio.

Materials of Design

Thursday, Oct. 22, 9:30 am - 12 noon

Chairman Anton De Sales Brasunas, ASM Metals Engineering Institute, Cleveland, Ohio.

High Temperature Corrosion Control by Alloying, by W. G. Renshaw, Allegheny Ludlum Steel, Brackenridge, Pa.

Control of Corrosion and Some Related Properties at High Temperatures by Means of Coatings, by W. N. Harrison, National Bureau of Standards, Washington, D.C.

Oil Ash Corrosion and Deposition, by A. D. Foster, General Electric Co., Schenectady, N.Y.

Materials of Design—Plastics, Part 2

Thursday, Oct. 22, 2 - 4:30 pm

Chairman Jean F. Malone, B. F. Goodrich Chemical Co., Cleveland, Ohio.

Plastics—A New Dimension in Building Materials, by R. T. Holtz, B. F. Goodrich Chemical Co., Cleveland, Ohio.

Considerations Involved in Choosing Plastic Pipe for Corrosion Control, by Leonard F. Sansone, Jr., U. S. Steel Corp., Pittsburgh, Pa.

Selection and Design of Structural Plastic Equipment, by Russell E. Gackenbach, American Cyanamid Co., New York, N.Y.

Cathodic Protection, Part 2

Thursday, Oct. 22, 2 - 4:30 pm

Chairman Jerome J. Pokorny, Cleveland Electric Illuminating Co., Cleveland, Ohio.

Cathodic Protection of Pipe-Type Cable, by D. E. Knauss and E. Beeman, Florida Power Corp., St. Petersburg, Fla.

Interference Problems on Underground Pipe Lines, by Art Erickson, Jr., Peoples Natural Gas Co., Pittsburgh, Pa.

Methods and Experiences in Underground Protection, by Oliver Henderson, Ohio Bell Telephone Co., Cleveland, Ohio, L. H. West, Standard Oil Co., Cleveland, Ohio, and P. P. Skule, East Ohio Gas Co., Cleveland, Ohio.

North Central Conference ABSTRACTS

Cathodic Protection

Cathodic Protection for Water Storage Tanks, by Herbert M. Patton, Jr., Brown Shoe Co., St. Louis, Mo.

Gives description and performance of cathodic protection systems installed in 40 different types and sizes of water storage tanks for plant sprinkler systems throughout the country during the last 12 year period.

Cathodic Protection for Hydraulic Structures in Fresh Water, by John L. Rohwedder, Corps of Engineers, Rock Island, Ill.

Describes 10-year corrosion control of submerged metal in hydraulic structures by means of cathodic protection. Trial installations on lock and dam structures were made in the Mississippi River. Information was obtained on anode location, anode material, anode supports, anode dimensions, current density, current distribution, straying of current, effectiveness of protection combined with underwater paint coatings and cost of cathodic protection. Design plans are given.

Methods and Experiences of the Ohio Bell Telephone Company in Cathodic Protection, by Oliver Henderson, Ohio Bell Telephone Co., Cleveland, Ohio.

Gives resume of company's experience in corrosion control on lead sheathed underground communication cables. Includes discussion of controlled drainage connections into all d-c railway sub-stations, rectifiers, magnesium anodes and magnesium ribbon to overcome anodic conditions. Also discusses survey methods for detection of galvanic hot spots along bare steel pipe lines and benefits and weaknesses of cathodic protection for gas services, distribution, transmission and storage lines.

Cathodic Protection of Pipe Type Cable Systems, by Edward R. Beeman and Donald E. Knauss, Florida Power Corp., St. Petersburg, Fla.

Describes cathodic protection of a coated pipe-type cable grounded to the power plant and station ground grids, having extremely low resistance to earth. Discusses quality of coating used and type of coating holidays initially located and those located after one year of service. Presents a study of portions of protective currents applied to cable and those sacrificed to the bare grounding metals. Pipe-to-earth potentials for first year are given.

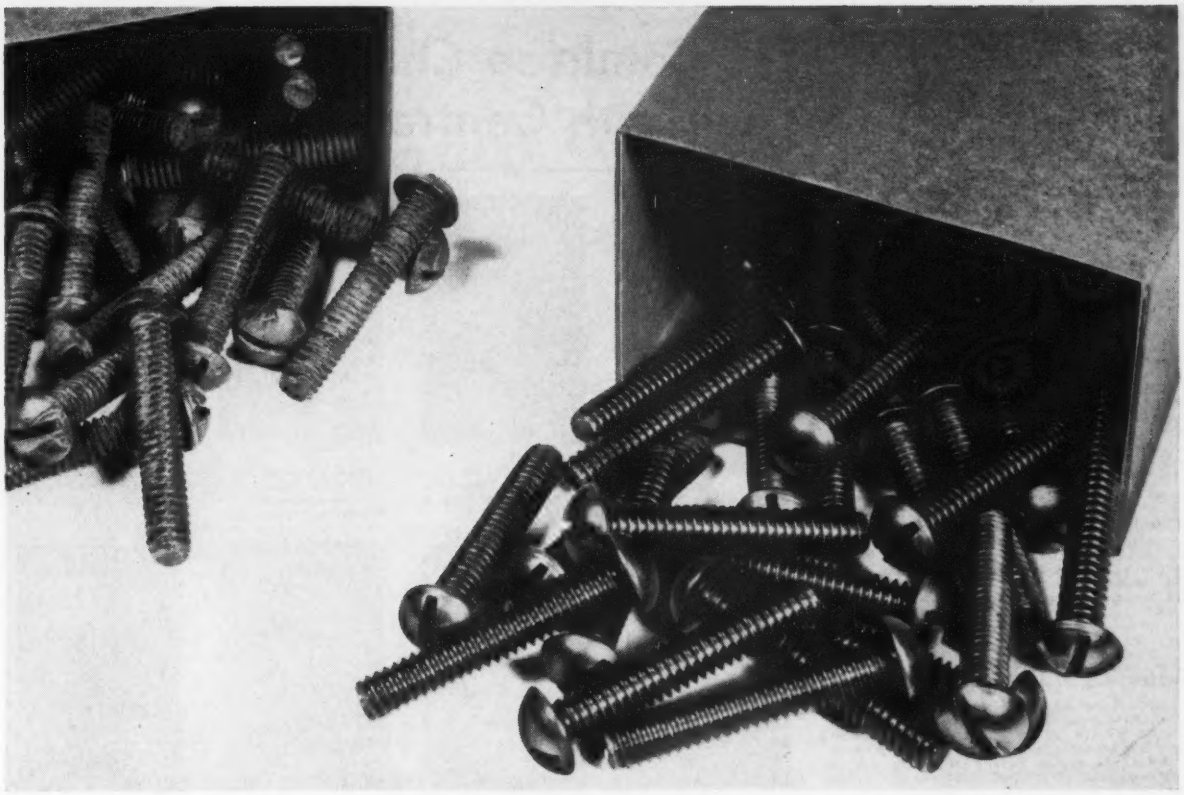
Interference Problems on Underground Pipe Lines, by C. A. Erickson, Peoples Natural Gas Co., Pittsburgh, Pa.

Discusses how difficult interference problems can be solved by proper design, cooperative attitudes and help of a coordinating committee.

Chemical Treatment

Thirty Years Experience With Silicates as Corrosion Inhibitors in Water Systems, by Henry L. Shuldener and Sidney Sussman, Water Service Laboratories, Inc., New York, N.Y.

(Continued on Page 86)



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North Central Conference ABSTRACTS

(Continued From Page 84)

Presents development of sodium silicates for controlling corrosion in water systems and how it is used for protection of galvanized iron, galvanized steel, yellow brass and copper water piping. Describes cases of poor results caused by improper feeding by dosing methods, piping defects, poor plumbing design or fabrication or improper operation of water system, particularly with respect to lack of hot water temperature control. Also describes the protective mechanism.

Four Years Experience in Treating a Cooling Water System for Corrosion Control, by W. A. Hess, Standard Oil Company of Ohio, Cleveland, Ohio.
Covers sequence of difficulties encountered in treating a cooling water system for corrosion control, which stemmed from a make up water of high hardness with a significant amount of dissolved hydrogen sulfide. Several equipment changes are described which were used to combat corrosion caused by condensers that had the cooling water on the shell side.

British-American Experience With Inhibitors in Low Temperature Service, by H. G. Bennett, British American Oil Co., Toronto, Canada.
Corrosion and fouling are reduced in overhead systems of crude, fluid catalytic cracking, furfural reforming and alkylation units by use of corrosion inhibitors. Describes injection methods used and measurement of treatment efficiency by metal analysis of tail waters, coupon surveys, corrosometer probe surveys and visual or caliper inspection.

Materials of Design

Oil Ash Corrosion and Deposition, by Allan D. Foster, General Electric Co., Schenectady, N.Y.
Gives a resume of residual fuel developmental work and operating experiences with an appraisal of future prospects. Results of recent additive tests conducted on residual fuel fired gas turbine units are included.

Control of Corrosion and Some Related Properties at High Temperatures by Means of Coatings by W. N. Harrison, Bureau of Standards, Washington, D. C.
Discusses use of ceramic coatings for corrosion protection in relation to other essential properties, especially as related to heat transfer.

High Temperature Corrosion Control by Alloying, by W. G. Renshaw, Allegheny Ludlum Steel, Brackenridge, Pa.
Describes how special modifications and alloying can provide a solution to the problem of high temperature corrosion.

Materials of Design—Metals

Polarization and Galvanic Corrosion, by T. P. May, International Nickel Co., Inc., Wrightsville Beach, N.C.
Severity of galvanic corrosion is affected by several factors such as galvanic potentials of metals and alloys, their polarization characteristics under influence of galvanic currents and conditions of exposure such as area ratios, conductivity of environment, etc. Polarization influence is largely due to cathode processes. Cathodic polarization of several materials in sea water are discussed in regard to behavior of materials when in galvanic contact with less noble materials.

Metals for Combatting Corrosion in the Process Industry, by F. L. Whitney, Jr., Monsanto Chemical Co., St. Louis, Mo.
Discusses performance of certain metals and alloys in typical chemical environments of the process industry. Reviews corrosion resistance, physical, mechanical and metallurgical considerations. Practical examples illustrate importance of investigating all aspects of the problem before proceeding with construction. Specific attention is given to temperature, heat flux, microstructure, heat treatment and chemistry of the metals and alloys.

Good Design Promotes Good Service, by E. D. Verink, Jr., Aluminum Company of America, New Kensington, Pa.
Enumerates examples of how good corrosion engineering has helped obtain good equipment life. Shows that understanding of potential causes of corrosion currents can avoid or eliminate operating difficulties by use of simple principles of design to prevent corrosion.

Materials of Design—Plastics

Design Considerations for Applying Reinforced Plastics for Corrosive Environments in the Process Industries, by F. W. Arndt, Heil Process Equipment Corp., Cleveland, Ohio.
Reviews design considerations for applying reinforced plastic materials of construction for corrosive service in process industries. Considerations regarding application, installation and basic design are discussed. Each of these considerations is related to case histories when possible.

Plastic Materials of Construction for Corrosive Environments—Their Testing and Evaluation, by Otto H. Fenner, Monsanto Chemical Co., St. Louis, Mo.
Relates testing and evaluation procedures followed by major chemical company's corrosion department in selecting plastics for severe services. Gives details of use of Instron Tensile Tester to furnish necessary physical properties change data as a supplement to appearance, volume change and percentage weight change data. Reviews various applications of plastics under unusual or borderline environments.

Use of Polyester and Epoxy Resin for Chemical Plant Repair, by W. A. Szymanski, Hooker Chemical Corp., Niagara Falls, N.Y.
Covers application of polyester and epoxy resin as repair material for chemical plant equipment such as piping, reactors, tanks, columns, etc. Also discusses reinforcing and fillers used and application techniques. Several case histories are given.

Selection and Design of Structural Plastic Equipment, by R. E. Gackenbach, American Cyanamid Co., New York, N.Y.
Discusses many criteria which must be considered in selecting and fabricating plastic material. Explains some design factors.

Considerations Involved in Choosing Plastic Pipe for Corrosion Control, by Leonard F. Sansone, Jr., U. S. Steel Corp., Pittsburgh, Pa.
Evaluation is made of properties of thermoplastic materials which make them useful for piping applications. Discusses outstanding property of plastic materials, their chemical resistance to broad range of inorganic and certain organic compounds. Test methods and various types of attack observed are given to help in choice of suitable material on basis of chemical resistance. Points out physical limitations of materials. Examples of several applications are given where plastic pipe has been used to solve corrosion problems.

Plastics—A New Dimension in Building Materials, by R. T. Holtz, B. F. Goodrich Chemical Co., Cleveland, Ohio.
Presents characteristics properties of significant plastic materials for building and discusses how they can be designed to improve performance in various building components. Major building components are discussed with respect to their primary functional requirements and performance problems. Shows how plastics can be used to overcome these difficulties. Reviews building provisions and commercial standards for plastics. Also gives installation costs and performance history compared to traditional materials.

Protective Coatings

New Developments in Protective Linings, by Wallace P. Cathcart, Tank Lining Corp., Pittsburg, Pa.
Discusses recent developments in protective linings for chemical processing and product storage and transportation facilities. Outlines newer plastics, inorganics, glass impregnation, combinations of film lining materials of different types to demonstrate their advantages and shortcomings. New methods of evaluating surface preparation and inspection techniques are discussed.

Sprayed Metals as a Base for Protective Coatings, by Engene C. Warner, Akron Sand Blast & Metallizing Co., Barberton, Ohio.
Discusses function of thin metallized coatings on iron and steel. Recommendations are made for proper surface preparation and application for flame sprayed metals. Explains action of sprayed zinc or aluminum in event of organic coating failure. Also discusses organic coating types used over sprayed metals including some over cathodic

(Continued on Page 90)

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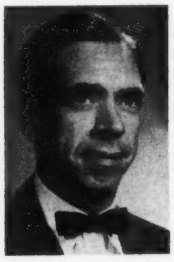

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Anode notes from
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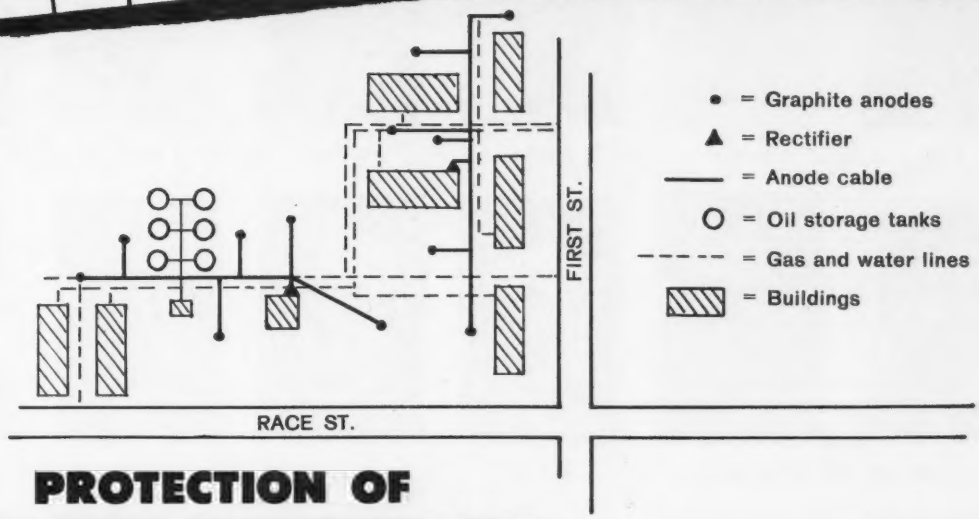
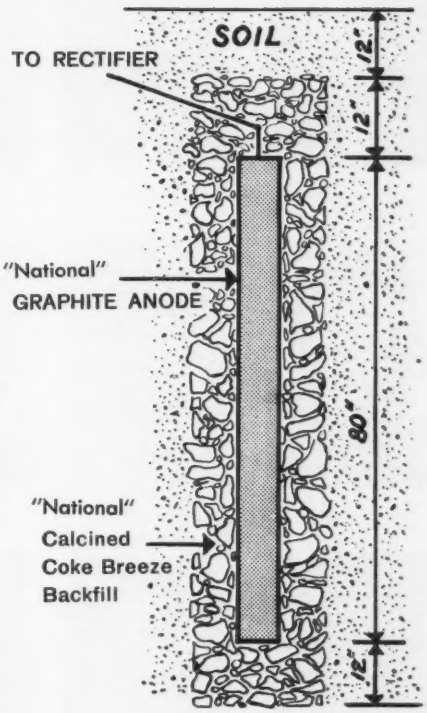


PROTECTION OF "IN PLANT" UNDERGROUND PIPING AND TANK BOTTOMS

The corrosion engineer of a large industrial products manufacturer with underground gas and water lines spread throughout a plant area of approximately 15 acres, was concerned with mounting maintenance costs. After a corrosion survey he decided to install an impressed current cathodic protection system with "National" Graphite Anodes and Carbonaceous Backfill.

In 1951, six inch and eight inch water lines were bonded to four inch gas lines and to six 25 foot diameter oil storage tanks. These in turn were connected to the negative sides of two 25 amp rectifiers. A distributed anode bed with six 2″ x 80″ graphite anodes installed in vertical holes 12″ diameter with carbonaceous backfill was connected to the positive side of each rectifier. The underground pipe lines and tank bottoms were brought to a minimum pipe to $CuSO_4$ half cell potential of .85 volts with a current output approximately 15 amps and 22 volts per rectifier. Later as the metal became polarized this current was reduced. In 1953, an additional graphite anode was installed to take care of stray currents coming from a railroad spur.

The impressed current cathodic protection system using "National" Graphite Anodes is still in operation, and the corrosion engineer advises that there has been a substantial reduction in the maintenance cost of their underground plant, which more than justified the cost of the installation.



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North Central Conference
BIOGRAPHIES

FRED W. ARNDT is chief engineer for Heil Process Equipment Corp., Cleveland, Ohio. He is a member of AICE and Cleveland Engineering Society and has a BS in chemical engineering from Pratt Institute and a MS from Stevens Institute of Technology.

EDWARD R. BEEMAN is corrosion engineer for Florida Power Corp., St. Petersburg, Fla. He has six years field experience in cathodic protection applications and formerly was associated with Harco Corporation and Consumers Power Corporation of Michigan. He is a member of NACE and has a BS in industrial management from Georgia Institute of Technology.

H. G. BENNETT is head of metals engineering at British American Oil Co., Toronto, Ontario, Canada. A member of NACE, he has been in the oil business 25 years and has been associated with his present company since 1934.

W. P. CATHCART has been president of Tank Lining Corporation since its incorporation in 1950. He has a BA from Washington and Jefferson College and has been active in NACE's Pittsburgh Section and technical committee work since 1950.

FRANCIS R. CHARLTON is manager of the Tar Coatings Group, Research Department, Koppers Co., Inc., Pittsburgh, Pa. Formerly he was associated with Imperial Chemical Industries and Pittsburgh Consolidation Coal Company. He has a BSc from Kings College, University of Durham, England.

CARL A. ERICKSON, JR., has been a corrosion engineer with People's Natural Gas Co., Pittsburgh, Pa., since 1947. He has a BA from Hobart College and a MS from the University of Chicago. He has been active in NACE technical committee work.

OTTO H. FENNER is affiliated with Monsanto Chemical Co., St. Louis, Mo. He has a BS in organic chemistry from Washington University. His NACE activities include technical committee leadership and help in organizing the Greater St. Louis Section.

ALLAN D. FOSTER is associated with the materials engineering sub-section of the Gas Turbine Department at General Electric Co., Schenectady, N. Y. He is a member of ASME and has a BS in metallurgy from Yale University.

R. E. GACKENBACH is associated with Organic Chemicals Division of America Cyanamid Co., New York, N. Y. He has a BS in metallurgical engineering from Lehigh University.

R. A. GARLING is a research and development laboratory supervisor for U. S. Stoneware, Stow, Ohio. His work includes product development and corrosion field testing of maintenance coatings and related products. He has a BS in chemistry from Lehigh University.

WILIAM N. HARRISON is chief of the Enameled Metals Section of the National Bureau of Standards, Washington, D. C. He has a BS from Virginia Polytechnic Institute and a MS from the University of Chicago. He received a Department of Commerce award for leadership in pioneer development of ceramic coatings for high temperature protection of steels.

OLIVER HENDERSON is an engineer with the Ohio Bell Telephone Co., Cleveland. He has a BS in electrical engineering from Case Institute of Technology.

W. A. HESS is a corrosion engineer with Standard Oil Company of Ohio. His work is in cooling water corrosion problems. A member of NACE, he was active in formation of Task Group T-5C-2 and has a BS in chemical engineering from Fenn College.

R. T. HOLTZ is affiliated with the sales and market development of plastics for building products with B. F. Goodrich Chemical Co. He is a chemical engineering graduate from the University of Wisconsin.

EVERETT D. HOOD is head of the Glidden Company's National Maintenance Laboratory, Cleveland, Ohio. He has a BS from Purdue University and formerly was associated with U. S. Rubber Company.

JOHN D. KEANE has been research director and executive secretary of the Steel Structures Painint Council, Pittsburgh, Pa., since 1957. He has been engaged in corrosion work for 10 years, has a BS in chemical engineering from Illinois Institute of Technology and formerly was employed by Armour Research Foundation.

DONALD E. KNAUSS has been with Florida Power Corp., St. Petersburg, for nine years. Presently he is in the transmission section of the Electrical Design Department. He has a BS in electrical engineering from Cornell University and is a member of AIEE and Cornell Society of Engineers.

N. A. MASON is assistant general manager of paint sales for Pittsburgh Plate Glass Co., Pittsburgh, Pa. He has been associated with the company since 1925 and has been supervisor of chemical resistant coatings sales. He has a BA from Abilene Christian College and a BBA from the University of Texas.

THOMAS P. MAY is manager of International Nickel Company's Kure Beach Testing Station on the North Carolina coast near Wilmington. Formerly he was head of the corrosion section at the Naval Research Laboratory in Washington. His NACE activities have included a directorship and a chairmanship of the publications committee.

C. G. MUNGER is vice president of manufacturing and research for Amercoat Corp., South Gate, Cal. He is a member of NACE and has been active as an officer and in technical committee work. He has a BS in chemistry from Claremont College.

HERBERT M. PATTON, JR., is chief engineer with Brown Shoe Company, St. Louis, Mo. He has a BS in engineering administration from Washington University. Formerly he was associated with General Steel Castings Corp., as supervisor of training.

WILLIAM G. RENSHAW is supervisor of the corrosion laboratory department at Allegheny Ludlum Steel Corp., Brackenridge, Pa. He has been with the company since 1940. He has written several technical papers on corrosion resistance of stainless steel and titanium.

JOHN L. ROHWEDDER is chief of the central paint laboratory, Rock Island District, Corp of Engineers, Rock Island, Ill. His principal fields of work are corrosion, soil mechanics and concrete. He has a BS in chemical enginering from the University of Iowa.

LEONARD F. SANSONE, JR., planning and development engineer with U. S. Steel's National Tube Division, Pittsburgh, Pa., is engaged in resin evaluation, process development and in preparation of plastics technical service data. He is a member of ASME and the Society of Rheology. He has a BS in engineering from Carnegie Institute of Technology.

G. G. SCHURR is assistant director of paint research at Sherwin-Williams Co., Chicago, Ill. He is a member of NACE, ACS, ASA, ASQC and ASTM. He has a BS from North Dakota Agricultural College. His field of work has been in metal protective paints and high polymer coatings.

HENRY L. SHULDENER is technical director and president of Water Service Laboratories, Inc., New York, N. Y. He has a BS in chemical engineering from New York University and has published works on use of silicate as a corrosion inhibitor and in corrosion of galvanized iron and yellow brass piping systems.

PETER P. SKULE is chief corrosion engineer for East Ohio Gas Co., Cleveland, Ohio. He has a BS in mechanical engineering from Case Institute of Technology and a LLB. He is a member of NACE and is currently secretary of the Cleveland Section.

SIDNEY SUSSMAN is chief chemist for Water Service Laboratories, New York, N. Y. He has a BS from Polytechnic Institute of Brooklyn and a PhD from MIT. He is a member of NACE, ACS and AWWA.

WALTER A. SZYMANSKI is head of the Corrosion and Materials Testing Laboratory at Hooker Chemical Corporation. Active in NACE, he has been appointed general chairman of the 1951 Annual NACE Conference to be held in Buffalo, N. Y. He has been chairman of the Niagara Frontier Section and is a member of several technical committees.

KENNETH TATOR is head of Kenneth Tator Associates, paint consultants in Corapolis, Pa. He has 30 years' corrosion experience with coatings and has been a NACE member since 1945. He has written several papers and holds patents on container linings, plastic products and corrosion barriers.

ELLIS D. VERINK, JR., is head of the chemical section, Development Division Aluminum Company of America. He has been a NACE director and Pitsburgh Section officer. He has a BS in metallurgical engineering from Purdue University.

EUGENE C. WARNER is president and general manager of Akron Sand Blast & Metallizing Co., Barberton, Ohio. He is a member of ASM and NACE.

L. H. WEST is affiliated with transportation department of Standard Oil Co., Fostoria, Ohio. He is chairman of the Toledo and Northwestern Ohio Committee on Corrosion, which recently joined NACE's T-7 Corrosion Coordinating Committee.

F. L. WHITNEY, JR., is corrosion consultant for the Engineering Department, Research and Engineering Division, Monsanto Chemical Co., St. Louis, Mo. He has been a president of NACE (1955-56) and has been active in sectional, regional and national affairs of the association. He has a BS in chemistry from Norwich University.

TECHNICAL REPORTS

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T-5B-2 Effect of Sulfide Scales on Catalytic Reforming and Cracking Units. Part 1—Metallographic Examination of Samples From a Catalytic Reforming Unit. Part 2—Intergranular Corrosion of 18-8 Cr-Ni Steel as a Result of Hydrolysis of Iron Sulfide Scale. A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Pressures and Temperatures in the Petroleum Industry. Per Copy $.50.

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North Central Conference ABSTRACTS

(Continued From Page 86)

metals. Presents an economic analysis for yearly cost of protection provided by combination of sprayed metal and organic coatings. Typical examples of applications will be given.

Selecting the Proper Specialty Coating for Corrosion Control, by R. A. Garling, U. S. Stoneware, Stow, Ohio.
Describes a general concept for preliminary evaluation of base properties of specialty coatings in relation to a specific problem. Gives general properties of synthetic elastomers, urethanes, silicones and inorganic binders.

A Comparison of Synthetic Resin Coating Materials, by C. G. Munger, Amercoat Corp., South Gate, Cal.
Reviews newer coating materials available. Shows where properties of each type best fits industry's requirements. Lists material properties and some factors which create coating failure. Explains that specific factors causing coating failure are basis for differentiating between various coatings and their effective use.

Shop Coating of Structural Steel, by John D. Keane, Steel Structures Painting Council, Pittsburgh, Pa.
Discusses principal methods of surface preparation, shop primers and selection of materials which should be considered for effective corrosion protection in shop applied coatings on structural steel.

Chemically Modified Coal Tar Coatings, by F. R. Charlton, Koppers Co., Inc., Verona, Pa.
Discusses chemistry and physical and chemical characteristics of chemically cured protective coatings resulting from combination of coal tar with three classes of reactive resins. These classes are diepoxides, polyepoxides and polyurethanes. Typical applications and service are described.

Epoxy Resin Protective Coatings, by N. A. Mason, Pittsburgh Plate Glass Co., Pittsburgh Pa.
Gives general description of various two-component epoxy protective coatings now offered for corrosion control. Discusses amine and polyamide cured coatings and compares their general characteristics. Includes methods of mixing, pot life and application procedures. Gives resistance ratings of epoxy coatings in comparison to other coatings in specific environments.

Protective Coating Testing by the Manufacturer, by G. G. Schurr, Sherwin-Williams Co., Chicago, Ill.
Two examples are described to show the range of testing of coatings done by the manufacturer. Discusses types of tests used and their results.

Protective Coating Testing by the User, by Kenneth Tator, Kenneth Tator Associates, Coraopolis, Pa.
Discusses various plant and field methods of evaluating industrial protective coatings, giving limitations and advantages of each. Gives suggestions for grading and other servicing of such evaluations and procedures for analyzing performance data. Also shows how data can be projected for paint protective life expectancies. Presents results obtained from evaluations in respect to performance of various generic types of coatings in various industrial exposures.

Drying Oil Coatings for Corrosion Protection, by E. D. Hood, Glidden National Laboratory, Cleveland, Ohio.
Discusses materials used in coating systems such as oil, alkyd, silicone alkyd, styrenated alkyd, vinyl toluene, isophthalic alkyd, phenolic, epoxy ester, modified epoxy ester, phenolic alkyd and vinyl alkyd. Outlines durability and chemical resistant properties of these systems. Also discusses development of these coatings through physical and chemical laboratory testing followed by field testing. Gives a case history of development of phenolic penetrating oil primers to improve humidity resistance, salt spray resistance, adhesion and general performance of drying oil coatings over wire brushed and sandblasted rusty steel.

The
HINCHMAN Corporation
Announces
Repeating courses in corrosion control.
Curriculum includes:
Corrosion Course for Engineers
Cathodic Protection Maintenance Course
Water Treatment Corrosion Course
Classes Begin October 12, 1959
Descriptive information furnished upon request
The Hinchman Corporation Engineers
1104 Francis Palms Bldg. Detroit 1, Mich.

South Central Conference ABSTRACTS

(Continued From Page 82)

problem conducted by the Cooling Tower Institute. Study included annual inspections of 103 towers and installation of 745 treated test panels of 4 species with 4 different preservative chemicals in 21 operating towers. Report includes data, pictures, correlations and recommendations.

High Temperature

High Temperature Corrosion in Nuclear Reactors, by W. O. Harms, University of Tennessee.
Briefly reviews experimental methods, results of testing programs and operating experiences in static and dynamic systems involving liquid metals and fused salts. Possible solutions to corrosion problems encountered are discussed in terms of basic reactions and surface phenomena which occur in these systems. Problems relating to temperature-gradient mass transfer and dissimilar-metal mass transfer in dynamic systems are considered in detail. Also discusses successful use of inhibitors in certain liquid metal systems.

Interested in Refinery Corrosion?
You will want to read (and keep for reference) three ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals papers:
An Industrial Experience of Severe Metal Wastage Resulting From Burning Methane With Oxygen
Metal Deterioration in Atmospheres Containing Carbon-Monoxide and Hydrogen at Elevated Temperatures
Corrosion in a Hydrocarbon Conversion System
These papers presented during Part 2 —Refinery Industry Symposium, NACE 15th Annual Conference at Chicago, March, 1959.
Scheduled for Publication in
DECEMBER CORROSION

North Central Conference Symposia Chairmen

Brasunas

Gegner

Hamel

Husock

King

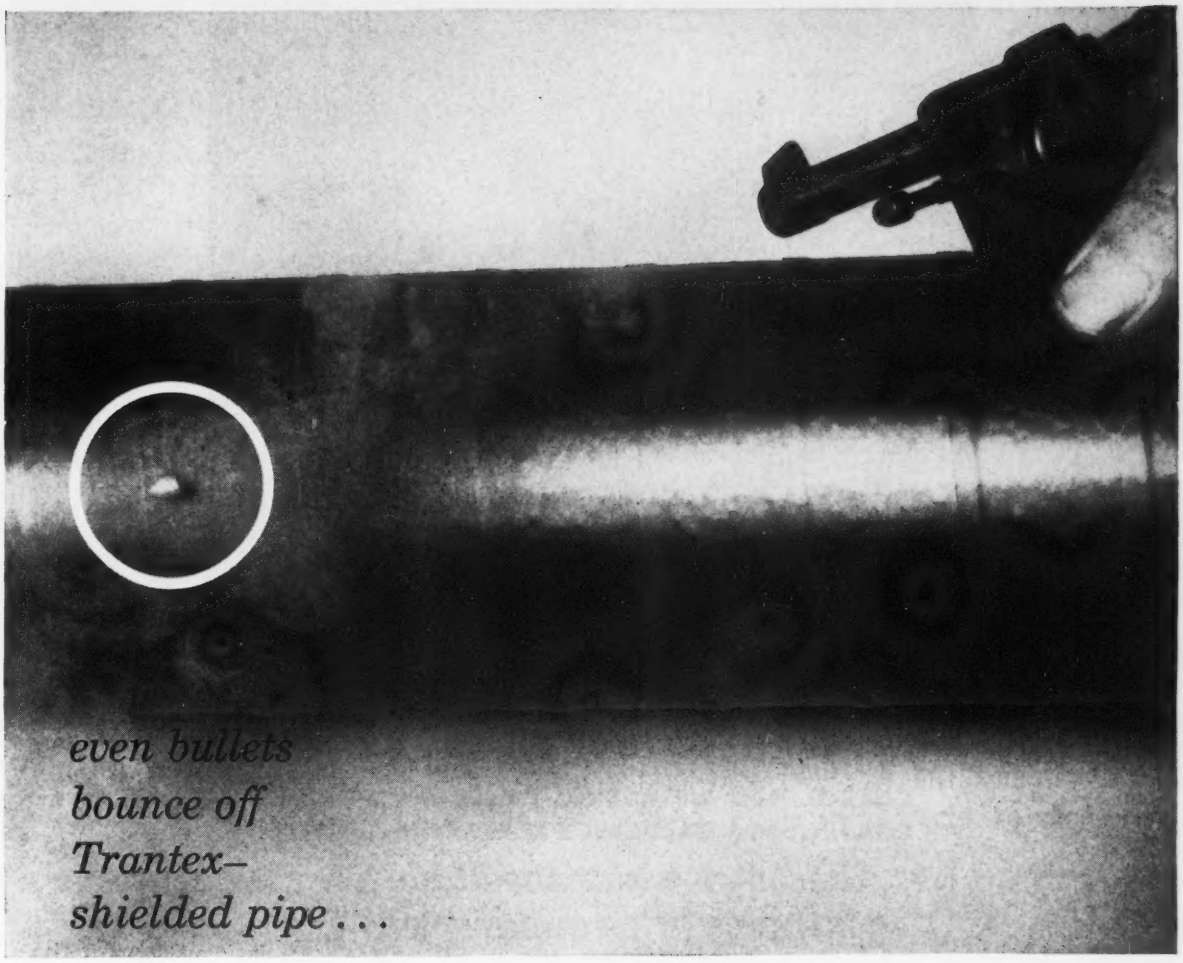
Malone

McIlrath

Canadian Region News

Edmonton Section heard Keith Wallam, chemical engineer with Shell Oil Company of Canada Limited, discuss oil field corrosion problems at the July 23 meeting.

Regular meeting date is the fourth Thursday of every month; meeting place is the Corono Hotel. Next meeting date is September 24.



TRANTEX®

resists abrasion, prevents penetration

Send today for free details

Specify TRANTEX, the illustrated 8-page booklet that outlines the many uses of Trantex, shows how it safeguards against corrosion above and below ground.

So tough that it resists a 22-calibre bullet fired at six feet, Johns-Manville Trantex pipe wrapping tape resists severe abrasive forces, prevents penetration by coarse backfill. Super-tough Trantex is ideal for protecting bends, welds and valves. It combats corrosion from all sources . . . resists water, air, micro-organisms, soil chemicals and attacks of stray electrical currents. Application is simple, by hand or machine. Because of a patented Johns-Manville bonding process, polyvinyl Trantex strips clean from the roll without delaminating, sticks tight to metal surfaces . . . provides lasting protection.

Put it to the test . . . super-tough Trantex, *the* tape for pipe wrapping.

JOHNS MANVILLE JM PRODUCTS

JOHNS-MANVILLE

JOHNS-MANVILLE DUTCH BRAND DIVISION
7800 S. Woodlawn Avenue, Chicago 19, Illinois

You could almost paint in the rain

with new **Carbo Zinc 11***

CARBOLINE'S NEW ZINC FILLED *INORGANIC* COATING FOR GALVANIC PROTECTION OF STEEL

Becomes water insoluble 20 minutes after application

Sudden rainfall, night condensation or rising tide will not wash it off or affect curing.

Carbo Zinc 11 is not only a new coating, it is a new *concept* in zinc filled inorganic coatings, with desirable properties not found in other protective coatings. In only 20 minutes the coating becomes insoluble in water. It can be applied directly to damp surfaces, in 90-100% humidity and at temperatures as low as 0°F.

Only one coat provides long-lasting galvanic protection to steel surfaces in marine, coastal and offshore environments. It is also insoluble in organic solvents, and is highly recommended for lining of solvent storage and cargo tanks. And look at its other outstanding characteristics:

- Prevents subfilm corrosion
- Excellent water, brine and solvent resistance
- Economical — low material, surface preparation and application costs
- Does not blister — cures from inside out
- No curing solution required
- Brush or spray application
- In non-immersion service, can be applied over a commercial blast, brush blast or wirebrushed surface

Write today for complete information, technical data, uses and sample of this remarkable new coating—Carbo Zinc 11.

**carboline COMPANY*

**Patent applied for*

32-A Hanley Industrial Ct.
St. Louis 17, Mo.

Specialists in Corrosion Resisting Coatings and Linings

GENERAL NEWS

PERIODICALS

Metal Finishing Abstracts. Bi-monthly Feb., Apr., June, Aug., Oct., Dec. Vol. 1, No. 1, Jan/Feb., 1959. 44 pages, 8 x 10½ inches. Robert Draper, Ltd., Kerbihan House, 85 Udney Park Rd., Reddington, Middlesex, England. Annual rate: Surface mail, $15; air mail, $20.

Informative abstracts taken from some 500 periodicals over the world on metal finishing. Also covered are patents, books and standards of all major industrial countries.

The classification "Corrosion and Electrochemistry" includes references to articles on films, mechanism of inhibitors, potential of metal surfaces, oxidation phenomena and others.

U. S. Translation Service Handles 35,000 Abstracts

The U. S. government's clearinghouse for translations of technical and scientific literature, the Office of Technical Services, recently began its second year of operation.

During its first year, 4055 complete translations and 35,000 abstracts of foreign technical literature, mostly Russian, were made available to the public. About 700 new titles are added to the collection each month.

Additional information can be obtained from the OTS, U. S. Department of Commerce, Washington 25, D. C.

Oct. 20-21 AEC Symposium

A two-day symposium for management and technical personnel on the reprocessing of nuclear fuels will be held at the Atomic Energy Commission on Oct. 20-21 at Richland, Washington. The cymposium is designed to review current technology for reprocessing spent fuels from research, test and power reactors.

Research Summary Printed

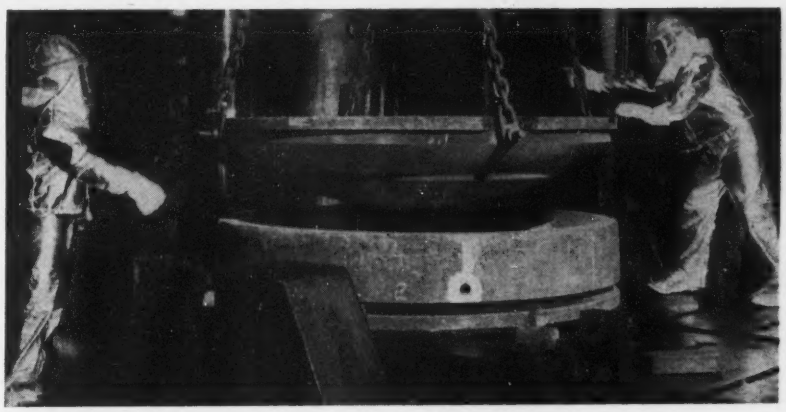
A summary of engineering research for 1957-58 at the University of Illinois Engineering Experiment Station has been published. Research areas covered are aeronautics, agriculture, ceramics, chemistry, civil, electrical, mechanical and mining engineering, physics and other miscellaneous areas.

Welding Bibliography

The 1958 Supplement to the American Welding Society Bibliographies is available at $1.50 per copy from Department T of the society at 33 West 29th St., New York 18, N. Y.

ASHRAE Secretary Named

Robert C. Cross has been appointed executive secretary of the American Society of Heating, Refrigerating and Air Conditioning Engineers.



FORGED BERYLLIUM SHIELD approximately 80 inches in diameter and 3 inches thick made from the die set shown above will be tested as part of the space capsule to be America's first manned space flight, Project Mercury. Workers are shown in aluminized suits guiding the top half of the die set into the bottom half. Called a "heat sink" by spacemen, the beryllium part will form the outside covering of the space capsule's floor. On the capsule's re-entry approach to earth, the blunt shield will be the chamber's leading face. It will store and dissipate the tremendous heat generated when the capsule dips into thick air while traveling at 18,000 mph.

Dates for International Corrosion Meetings Given

Some of the international meetings of interest to corrosion engineers listed in Cebelcor's (Belgian Center for the Study of Corrosion) calendar are given below:

Sept. 29-Oct. 2—11th Meeting of the International Committee on Thermodynamics and Electrochemistry, Vienna.

Oct. 19-21—International Symposium on the Aging of Plastic Materials, Dusseldorf, Germany.

Oct. 20-23—Diamond Jubilee, International Clean Air Conference and Exhibition, London.

Dec. 3-5—3rd International Conference on Non-Destructive Testing Methods, Tokyo, Hakone and Osaka, Japan.

April 7-8, 1960—European Symposium on Cathodic Protection, sponsored by European Federation on Corrosion, Frankfort, Germany.

Sept., 1960—Symposium on Inhibitors, Ferrara, Italy.

Metallurgical Society

Residual Stresses in Cold Rolled and Temper Rolled Strip will be one of the papers presented at the January 20, 1960, conference of the Mechanical Working Committee, Iron and Steel Division of the Metallurgical Society. The conference will be held at the Del Prado Hotel, Chicago, Ill.

Radioisotope Training

The Atomic Energy Commission has organized a program to provide students at small undergraduate colleges the opportunity for specialized training in the techniques of using radioisotopes.

A bus will be used for the mobile laboratory which will move to college campuses for a two-week course.

BOOK NEWS

Radioisotopes for Industry. 190 pages, 5 x 7⅜ inches, cloth. By Robert S. Rochlin and Warner W. Schultz. 23 June, 1959. Reinhold Publishing Corp., 430 Park Ave., New York 22, N. Y. Per copy $4.75.

A generalized and comprehensive discussion of the subject. Book is amply illustrated and has appendices listing useful radioactive isotopes, technical aspects of radioactivity and activation by thermal neutrons. An extensive bibliography is given in Appendix D.

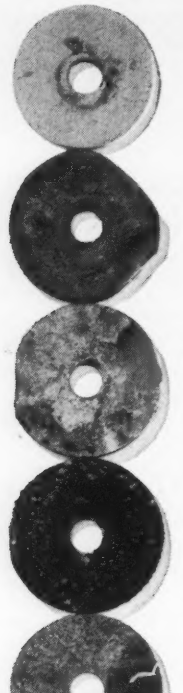
Contents include gaging without contact, radiography and autoradiography, wear measurement, activation techniques, using tracers in research and development, using radioisotopes in manufacturing; equipment, facilities and training; protection from radiation hazards, present trends and future possibilities. There is an alphabetical subject index.

Report on Properties of Cast Iron at Elevated Temperatures. Prepared by J. R. Kattus and Bryan McPherson. 90 pages, 8½ x 11, paper. March, 1959. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per Copy, $4.25.

Six commercial low-alloy gray irons and one unalloyed ferritic nodular iron are evaluated at 800 and 1000 F by means of tensile tests, creep rupture tests, thermal shock tests, growth tests and metallographic examinations.

It is concluded that generally alloys are promising for long-time load-carrying applications and for applications involving thermal shock at temperatures up to 800 F but not at 1000 F. The tests indicate development of low-alloy cast irons suitable for 1000 F use is conceivable. Value of alloying elements is given. Five alloys are suggested as suit-

(Continued on Page 94)



Which valve alloy?

Corrosion testing, which often includes analysis of test specimens like those shown above, insure Aloyco valve customers of the right alloy for each job. Typical metals used in Aloyco Valves: Types 304 and 316 Stainless Steel, Aloyco 20, Nickel, Monel, Hastelloy B, C and D.

At Aloyco, 30 years experience in stainless steel valves exclusively is at your service. Our field consulting service is yours for the asking.

On your next valve job call in the specialists . . . write Alloy Steel Products Company, 1304 West Elizabeth Avenue, Linden, New Jersey. 9.14

Longer Lasting ALOYCO VALVES

ALLOY STEEL PRODUCTS COMPANY
Linden, New Jersey

AEC Awards 22 Contracts

The Atomic Energy Commission has awarded 22 contracts to develop new and improved industrial uses of radioisotopes and high level radiation.

Totaling approximately $800,000, the contracts were awarded to educational institutions, industrial firms and private laboratories.

24th IEC General Meeting

The 24th general meeting of the International Electrotechnical Commission met June 30-July 10 in Madrid, Spain. About 700 delegates attended. A meeting of the IEC Council and about 30 technical committees and subcommittees were included.

Ohio State Engineering

Reorganization of Ohio State University's College of Engineering has established a Pre-Engineering Division for the first two years of pre-professional study and a Professional Division for the last three years of the five-year program.

BOOK NEWS

(Continued From Page 93)

able for 10-year service at 800 F under loads in tension from 15 to 30,000 psi.

The 46 references appended do not include any of the several articles concerning high temperature properties of cast irons published in CORROSION.

Sixth Report of the Corrosion Committee. Compiled by J. C. Hudson. 217 pages, 5¼ x 8½ inches, cloth. 1959. The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W. 1., England. Per copy, Pounds Sterling 3 plus 3 shillings.

This report summarizes the work of the British Corrosion Committee since its last report in 1938. Concise information is given on work undertaken by the committee including reports on some of the tests underway and incomplete at the time of the fifth report.

Subjects include: Atmospheric corrosion, corrosion by industrial waters, marine corrosion, soil corrosion, protective coatings, corrosion test procedures.

A section on atmospheric corrosion tests includes the following subjects, general experimental procedure, tests on bare irons and steels, effect of climate, tests on painted irons and steel, paint trials on iron and steel stands and conclusions.

A section on atmospheric corrosion and protection at temperatures up to 300 C covers the following subjects: Experimental program, assessment of corrosion conditions, tests on bare materials, coatings, results of tests on small specimens of sheet, vitreous enamels, patch-painting tests on strip, tests on full-sized sheets, laboratory tests, conclusions.

The section headed marine corrosion service trials covers surface preparation, comparison of compositions, service experience.

The final section covers terms of reference, acknowledgments, a bibliography of the committee's publications and a bibliography of anti-fouling research.

Numerous tables give analyses of materials tested, compositions of coating materials, characteristics of test sites, results of tests of bare and coated materials, effect of millscale, effect of surface condition, results of tests on commercial low-alloy steels, analyses of rusts, corrosion-time tests by the decrease-in-breaking load method, analyses of water from deposit gauges, comparison of sulfur pollution and corrosion rate, observations of copper-steel specimens, results on zinc specimens, results of tests on painted specimens, lives of painting schemes and others.

Anti-Corrosion Manual, 1959 Edition. 324 pages, 8¼ x 11¼, cloth. 1959. Corrosion Prevention and Control, 97, Old Brompton Rd., South Kensington, London, S.W. 7. Per copy, plus postage, Pounds Sterling, 3.

In addition to sections reproduced from the 1958 edition, new chapters have been added. These include sections on asbestos, clad steel, derusting, aluminum paints, primers, application methods, pipe coatings and tapes and others. A list of British standards also has been added.

There are about 180 advertisements interspersed among the text pages.

Second Interim Report on Use of High Silicon Cast Iron for Anodes. Report of NACE Technical Unit Committee T-2B on Anodes for Impressed Currents. Pub. No. 59-16. 12 pages, paper, July 1, 1959. National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2 Texas. Per Copy, $1.50 to members, $2.00 to non-members.

Data from more than 250 separate installations are collected, analyzed and tabulated, continuing information presented in the first interim report. Considered separately are ground beds, fresh water service and salt water service. The report says data support earlier evidence that corrosion of anodes is negligible in coke breeze backfill. Service in fresh water is generally good except at temperatures in the 160-200 F range. Molybdenum appears to have effect of extending service life.

In salt or brackish water evidence indicates that molybdenums additions are beneficial in extending life, especially at higher temperatures. Regular high silicon anodes are not recommended for use in low resistivity salt water.

Third Interim Report on Use of High Silicon Cast Iron for Anodes. Report of Technical Unit Committee T-2B on Anodes for Impressed Current. Pub. No. 57-17. 13 pages, paper, July 1, 1959. National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas. Per Copy, $1.50 to members; $2 to non-members.

Reports of data received in reply to questionnaires circulated by Task Group T-2B-4 during 1957 are reported. Data show no appreciable difference exists in performance of high silicon cast iron and graphite in a well tamped coke breeze backfill. Results indicate high silicon iron possesses excellent resistance to various fresh water under normal temperature conditions. High silicon iron containing molybedenum shows better performance than regular alloy under adverse salt water conditions.

General results of this survey are divided into three groups: ground bed, fresh water and salt water applications. Tables are included giving typical installations for each group.

Lubricating Conference

Basic friction and wear will be among the general subjects to be discussed at the 6th Annual Conference on Lubrication to be held October 20-22 at New York City's Sheraton-McAlpin Hotel.

The conference is sponsored jointly by American Society of Lubrication Engineers and American Society of Mechanical Engineers.

Plastics Engineering

"Plastics Engineering—State of the Art Today" will be the theme of the first National Technical Conference of the Society of Plastics Engineers scheduled for Oct. 13-14 in Los Angeles, Cal.

One of the papers scheduled of probable interest to corrosion engineers is titled "Laboratory and Field Evaluation of Plastics Piping Systems," to be presented by Martin Usab of Rexall Drug & Chemical Co.

Fuel Element Instability

Fuel element instability which is hindering progress toward economic atomic power will be discussed during the November 2-5 meeting in Chicago of the Metallurgical Society of AIME, as part of the National Metal Congress.

Engineering Films

The International Film Festival for Mechanical Engineering Science will be held October 4-17 in Budapest, Hungary. It is sponsored by the Hungarian Scientific Society for Mechanical Engineering.

Quality Control Meeting

Third Annual Chemical Division Technical Conference of the American Society of Quality Control will be held September 24-25 at the Shamrock Hilton Hotel in Houston, Texas.

Quality control problems of the chemical and process industries will be discussed during the technical program.

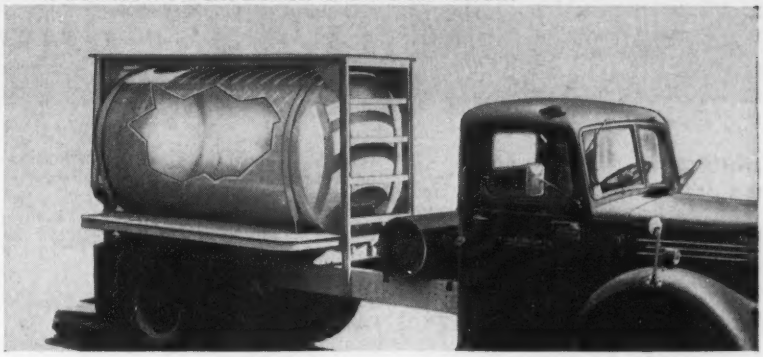
15th Magnesium Convention

Fifteenth Annual Convention of the Magnesium Association will be held Oct. 19-20 at the Hotel Roosevelt in New York City. Theme will be "Magnesium Techniques and Trends—A Review and Projection."

how CORROSION is indexed

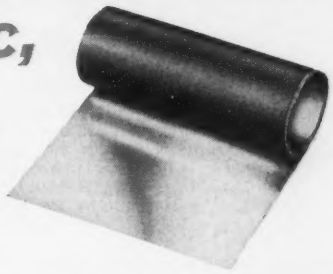
- By Volumes Annually in December Issue
- In NACE Bibliographic Surveys of Corrosion
- In NACE Abstract Punch Card Service
- In 10-Year Index to CORROSION
- In Engineering Index
- In Applied Science and Technology Index

A CHEMISEAL FLUOROCARBON LINING CASE HISTORY



Wyman-Gordon *finds economical answer to handling*

Hydrochloric, Hydrofluoric, Nitric Acids



Chemiseal Fluorocarbon Linings are chemically-inert, tough, and withstand heat and cold (−320° F. to +250° F.).

A CHEMISEAL FLUOROCARBON PLASTIC LINING is used on this truck owned by Wyman-Gordon of Worcester, Massachusetts to assure safe, economical haulage of waste acids. Since April, 1957 the truck has been in continuous service carrying 80% hydrochloric, 13% hydrofluoric, and 7% nitric acid between the company's two Closed Die Forging plants and the disposal area. And the lining is still in perfect condition.

You can make your present plant equipment impervious to acids by applying CHEMISEAL Fluorocarbon Plastic Linings. They can be cemented over most contours and to most materials—metal, wood, concrete, etc. And, to make protection complete, seams are heat fused into a continuous, chemically-inert surface.

CHEMISEAL Fluorocarbon Plastic Linings are available through certified applicators, equipped with factory-trained personnel and specialized equipment. Call the applicator nearest you for more information:

THE BARBER-WEBB COMPANY, INC., LOS ANGELES, CAL.
BELKE MFG. CO., INC., CHICAGO, ILLINOIS
BUCKLEY IRON WORKS, DORCHESTER, MASS.
ELECTRO-CHEMICAL ENGRG. & MFG. CO., EMMAUS, PA.
LINCO, INC., HOUSTON, TEXAS
METALWELD, INC., PHILADELPHIA, PA.

Or write for Bulletin AD-152. Special Products Dept., United States Gasket Company, Camden 1, New Jersey.

United States Gasket *Plastics Division of* **GARLOCK**

Equipment Services NEW PRODUCTS Materials Literature

Agitators

Steam Jet Agitators, made by Heil Process Equipment Corp., Cleveland, Ohio, inject air into solutions to produce efficient agitation and uniform heating. Nozzles of various materials are available.

Aluminum

Air Conditioner Coils made of aluminum are being field tested on about 3000 units by Aluminum Company of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa. Good performance of the coils in corrosive environments and a new zinc soldering process make the use of aluminum in the coils possible.

•

Aluminum Jacketing with a factory baked enamel color finish was used over insulation on process vessels and pipelines in Superior Oil's new Lowry gas processing plant near Lake Arthur, La. Colorweld aluminum, made by Reynolds Metals Co., was used.

•

Aluminum Roof for the Lincoln Continental is being tested by Ford Motor Company's Lincoln Division. Thirty-five pounds lighter than a steel roof, the aluminum has a brushed finish.

Anodes

Anodes and Plating Chemicals offered by Hanson-Van Winkle-Munning Co., Matawan, N. J., are described in Bulletin No. AC-111 available from the company. Criteria for anodes, specifications and composition are given.

Bearings

DU Dry Bearing Material, marketed by United States Gasket Co., Camden 1, N. J., is being used in the manufacture of thrust washers to improve dry bearing operation. DU is a patented composite material consisting of a steel backing with a thin sintered porous bronze powder filled with Teflon. It withstands temperatures from —328 to 536 F, according to the manufacturer.

Cathodic Protection

One Shot Mold is a ceramic disposable unit for connecting cable to ground rod. Manufactured by Erico Products, Inc., 2070 E. 61st Place, Cleveland, Ohio, the mold is an adaptation of the Cadweld process and replaces the familiar semipermanent graphite mold and handle clamp.

Ceramics

Pyroceram Materials, available from Corning Glass Works, are described in a brochure available from Director of Marketing, Corning Glass Works, Corning, N. Y. Included are electrical, mechanical, thermal and chemical properties and effects of high energy radiation.

•

Republic Hardfacing Corp., 479 Broadway, Bedford, Ohio, has introduced a new hardfacing process which is spray welding with a ceramic powder. Spray welded Cermet fuses with the parent metal and stops the burning effects of exhaust gases, erosion and corrosion on engine valves, according to the manufacturer. Cermet is also being used in the jet engine field.

Cleaners

Foam Solvent is pumped from an apparatus directly into tanks, pipe or tower that is to be cleaned by a new process used by Dowell Division of Dow Chemical Co., Tulsa, Okla. When the vessel being cleaned is filled with the chemical foam, the process continues with the foam passing into a foam breaker and filter to remove material dislodged. After-rusting problems can be eliminated because the cleaned metal surfaces are not exposed to air during the cleaning process. Foam solvent is displaced directly with a foam rinse or flush and by a foam passivator.

Coatings—Organic

Professional Paints Company, Denver, Colo., has been appointed distributor of Truscon Laboratories' products in the Rocky Mountain area.

•

Tygon Vinyl Plastic Coating applied hot to a thickness of 5 mils over a sandblasted and primed metal surface is being used to protect commercial and industrial steel windows and doors manufactured by Standard Products Co., 4662 Puttygut Rd., St. Clair, Mich. The coating system, developed by U. S. Stoneware, Co., Akron, Ohio, dries almost instantly to form a hard gloss coating resistant to moisture, acid and alkali fumes and condensates.

•

Spray-On, Strip-Off Coatings are described in a brochure published by Spraylat Corp., 1 Park Ave., New York 16, N. Y. Advantages are explained of strippable coatings in protecting sensitive finishes of metals, plastics, glass, rubber, ceramics and painted surfaces against weathering and abrasion.

•

Alpex, the Cyclized Rubber in Protective Coatings, a booklet describing the properties and uses of Alpex in the formulation of chemically resistant coatings is available from Alkydol Laboratories Div., Reichhold Chemicals, Inc., 3242 South 50th Ave., Cicero 50, Ill. Data were collected over 15 years on field and laboratory evaluations.

Filters

V. D. Anderson Company, division of International Basic Economy Corp., 1935 West 96th St., Cleveland 2, Ohio, has published a catalog of purifiers, separators, mist extractors and scrubbers. It is designed for engineers, operating executives and purchasing agents. Specifications and operations of Anderson purifying equipment are given.

Floors

Tufcrete Resurfacer for repair of concrete, wood, brick, asphalt and composition floors is explained in bulletins available from Tufcrete Co., Inc., 502 East Locust St., Des Moines 9, Iowa.

•

Masterplate Iron Clad concrete floors are described in a brochure available from Master Builders Co., Cleveland 3, Ohio. Characteristics of the floors are given such as wear and corrosion resistance, economy for industrial floors subjected to heavy use.

Glass

Kimax Glass Pipe and Fittings, made by Kimble Glass Co., and distributed by Glass Products Division of Fischer & Porter Co., Hatboro, Pa., are manufactured from KG-33 borosilicate glass. They have corrosion, chemical and heat resistance and are transparent.

Instruments

Tubescan 105 is an electronic instrument for accurate inspection of the internal surface condition of tubing and piping. Made by Union Industrial Equipment Corp., 40 Beech St., Port Chester, N. Y., the instrument permits determination of pitting, bulging, concentric and eccentric corrosion and combinations of these in tube diameters from 2 to 10 inches.

•

High Temperature Solenoid which operates continuously at ambient temperatures to 1000 F has been developed by Rocker Solenoid Co., a subsidiary of Telecomputing Corp., 140 North Marine Ave., Wilmington, Cal. It was designed for aircraft and missile applications where engine or re-entry temperatures make ordinary solenoids inoperative.

•

Typewriters which have all parts of heat dried chrome, nickel or steel or protected with a minimum of 3 coats of enamel are manufactured by Siemag of West Germany and distributed in the U. S. by Continental Office Machines, Inc., 500 Fifth Ave., New York 36, N. Y. The typewriter is coated with a chemical compound which resists salt, water, air, corrosion and rust.

•

Permeter, a hand perspiration tester, is being distributed by Ameresco, Inc., 7 Center Ave., Little Falls, N. J. The instrument is designed for quality control use to detect personnel with excessive hand perspiration. It contains a built-in power source and is about the size of the average flashlight.

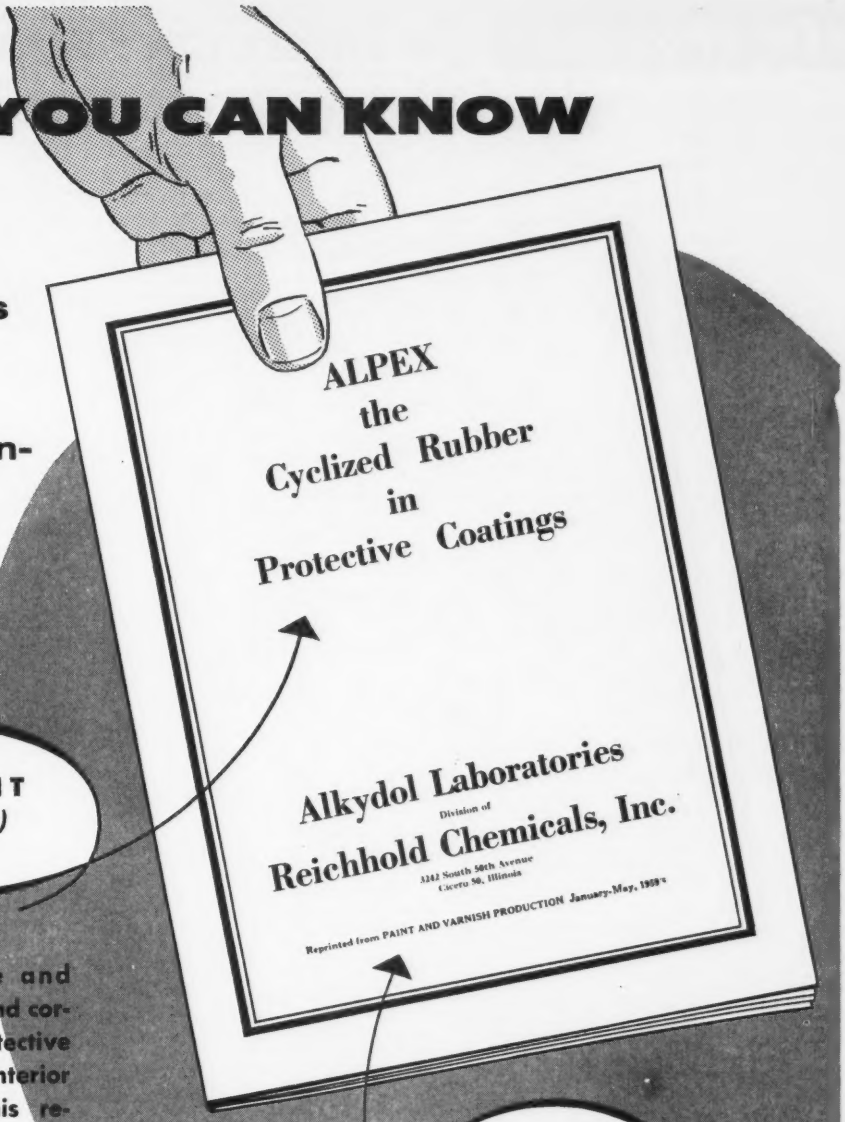
Iron

Mn Wrought Iron, named for its principal alloying element manganese, has been developed by A. M. Byers Co., Clark Bldg., Pittsburgh, Pa. It possesses the corrosion resistance, weldability and working properties of 4-D wrought iron plus better impact and lower temperature properties than most steels, according to the company.

(Continued on Page 98)

NOW YOU CAN KNOW

the proved facts about **ALPEX** for corrosion-resistant protective coatings



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NEW PRODUCTS

(Continued From Page 96)

Mastic Extruder

New Mastic Extruder is being manufactured by Machine and Instrument Development Corp., 16343 Euclid Ave., Cleveland, Ohio. The machine is semiportable for on-the-job use and is designed to extrude heavy mastic sealing compounds for tape or ribbon sealing applications. Die plates can be changed to extrude various shapes and cross sections. Only slugs or billets of mastic material need be stocked.

Mergers

Controlling Interest in Magna Products, Inc., 11808 S. Bloomfield Ave., Santa Fe Springs, Cal., producer of specialty chemicals and electronic instruments for oil, gas and chemical industries, has been acquired by Thompson Ramo Wooldridge, Inc., Anaheim, Cal.

•

American Pipe and Construction Company of Monterey Park, Cal., and Nukem Products Corporation of Buffalo, N. Y., have completed a merger designed to provide increased facilities on two coasts of each company's activities in the field of corrosion resistant products.

Metallic Mixtures

Lead Cemented Alloys made by mixing molten lead with finely divided solid particles of other metals or materials has been demonstrated at Battelle Memorial Institute, 505 King Av., Columbus 1, Ohio. The resulting material combines properties of both lead and the second substance, usually a metal. This research was sponsored by the Lead Industries Association.

Metals—Ferrous

Stainless Steel Mufflers in automobiles are being tested by Allegheny Ludlum Steel Corp., Oliver Bldg., Pittsburgh 22, Pa. Tests indicate that these mufflers may last the lifetime of the car.

•

Aluminized Steel is being used in refuse burners manufactured by Wilco Machine Works, Inc., Municipal Airport, Memphis 14, Tenn. It resists rust and other forms of corrosion and erosion for longer service life, according to the fabricator.

Miscellaneous

Odorless Deodorant, being made by National Cylinder Gas Division of Chemetron Corp., does not have a perfumed masking scent nor a chemical to paralyze the sense of smell. It works by fixation, a chemical reaction with the odor absorbing itself, according to the manufacturer.

•

Steelbestos, an asphalt-impregnated, asbestos-protected material, is being manufactured by American Steel Band Company, Pittsburgh, Pa. It is designed for use as a corrosion resistant roofing and siding material.

Painting Equipment

Airless Spray Painting Equipment has been developed by Devilbiss Co., Toledo, Ohio, which forces the paint through a small orifice at 1800 to 2400 psi. When the paint is released from the pressure, it expands and breaks into small particles with enough forward velocity to carry them to the surface being painted.

Plastics

Hycar Rubber Guides for sucker rods used in drilling operations have been developed by Oil States Rubber Co., Arlington, Texas. The guides are designed to snap on sucker rods to keep them centered in well casings and to eliminate metal-to-metal contact many chemical corrosion problems for longer rod and casing life. They are produced from Hycar nitrile rubber, manufactured by B. F. Goodrich Co., 3135 Euclid Ave., Cleveland 15, Ohio.

•

P-F Plastic Film Dust Boot is available from A. F. Gagne, Associates, 50 Wall St., Binghampton, N. Y. It is designed as a seal on reciprocating rods to eliminate corrosive liquids, abrasive grits, dusts and sludges.

•

Tubing Inserts designed to protect the inlet section of tubes against wear and damage caused by erosive conditions are described in Bulletin P-335 available from Crane Packing Co., 6400 Oakton St., Morton Grove, Ill. Inserts are available in nylon polyethylene and phenolic resin for resistant to corrosion and chemical and fungus attack.

•

High Strength Plastic Clamps made of ethyl cellulose and ribbed for extra strength by an extrusion process are being produced by Wm. Dudek Mfg. Co., 4901 West Armitage, Chicago 39, Ill. They are available in a variety of standard sizes, both round and flat. Custom dimensions are fabricated to specification.

•

Fluoroflex-T Sparger Assemblies with a steel reinforcement have been developed by Resistoflex Corp., Roseland, N. J. The new type LS sparger is of laminated Teflon and glass fabric construction with a steel reinforcing tube built inside the wall.

Products List

Denso Products, a line of anti-corrosion and waterproofing products manufactured in England, are being distributed in the U.S.A. by Denso, Incorporated, 408-414 Chestnut St., Camden, N. J. A list of the products is available from the company.

Pumps

Solution Feed Pumps that can be used for chlorinating home well water systems for introducing phosphate or mild alkali treatment to control scale, corrosion and red water are available from Calgon Co., Box 1346, Pittsburgh 30, Pa. Called the No. 77 Solution Feeder, the small diaphragm pump has a feed rate adjustable from 1 pint to 3 quarts per hour and will feed into any water line having pressures to 100 psi.

•

Spirit Model Submersible Pumps have been developed by Continental Pump Co., 1027 S. Vandeventer Ave., St. Louis 10, Mo. They incorporate a simple helical screw principle of a single corrosion resistant rotor turning within an abrasion resistant stator.

Valves

Milton Roy Company, 1300 E. Mermaid Lane, Philadelphia 18, Pa., has developed PVC relief and back pressure valves for corrosion resistant applications not covered by other valves. The relief valves can withstand pressures to 400 psi at 68 F and 200 psi at 140 F. The back pressure valves withstand pressures to 200 psi at 140 F.

Waste Disposal

Somat Waste Disposal System is described in a brochure available from Wandel Machine Co., Pomeroy, Pa. The Somat chews refuse, garbage and paper waste into fine, compacted pulp, eliminates odors by chemical treatment and discharges the waste in haul-away containers.

Water Displacing

Enthone Water Displacing Liquid No. 1, an organic solvent used for rapid shedding from metals, is being produced by Enthone, Inc., New Haven, Conn.

MEN in the NEWS

Robert L. McGlasson, NACE member, has been promoted to senior research metallurgist in Continental Oil Company's production research division at Ponca City, Okla.

•

James A. Main has been named manager of the industrial division of Flintkote Company in New York City. Three departmental managers have been named under him: **A. J. Healey** for automotive and railway products; **C. Seibel, Jr.,** for paving products and **W. H. Mortonson** for industrial products.

•

Murray Newell is the new sales representative for Royston Laboratories, Inc., covering Florida, southern Alabama and southern Georgia. He will be located at the new sales office in St. Petersburg, Fla.

•

Allan Ray Putnam has been appointed managing director of the American Society for Metals.

•

Alan G. Richards has been elected vice president of Bjorksten Research Laboratories, Madison, Wis.

•

William A. Roach, Jr., has been appointed product manager at J. E. Lonegan Co., 211 Race St., Philadelphia 6, Pa.

•

Robert R. Schneider has been appointed Central Region Manager of Flexonics Corp., 1500 Trombly Ave., Detroit 11, Mich.

•

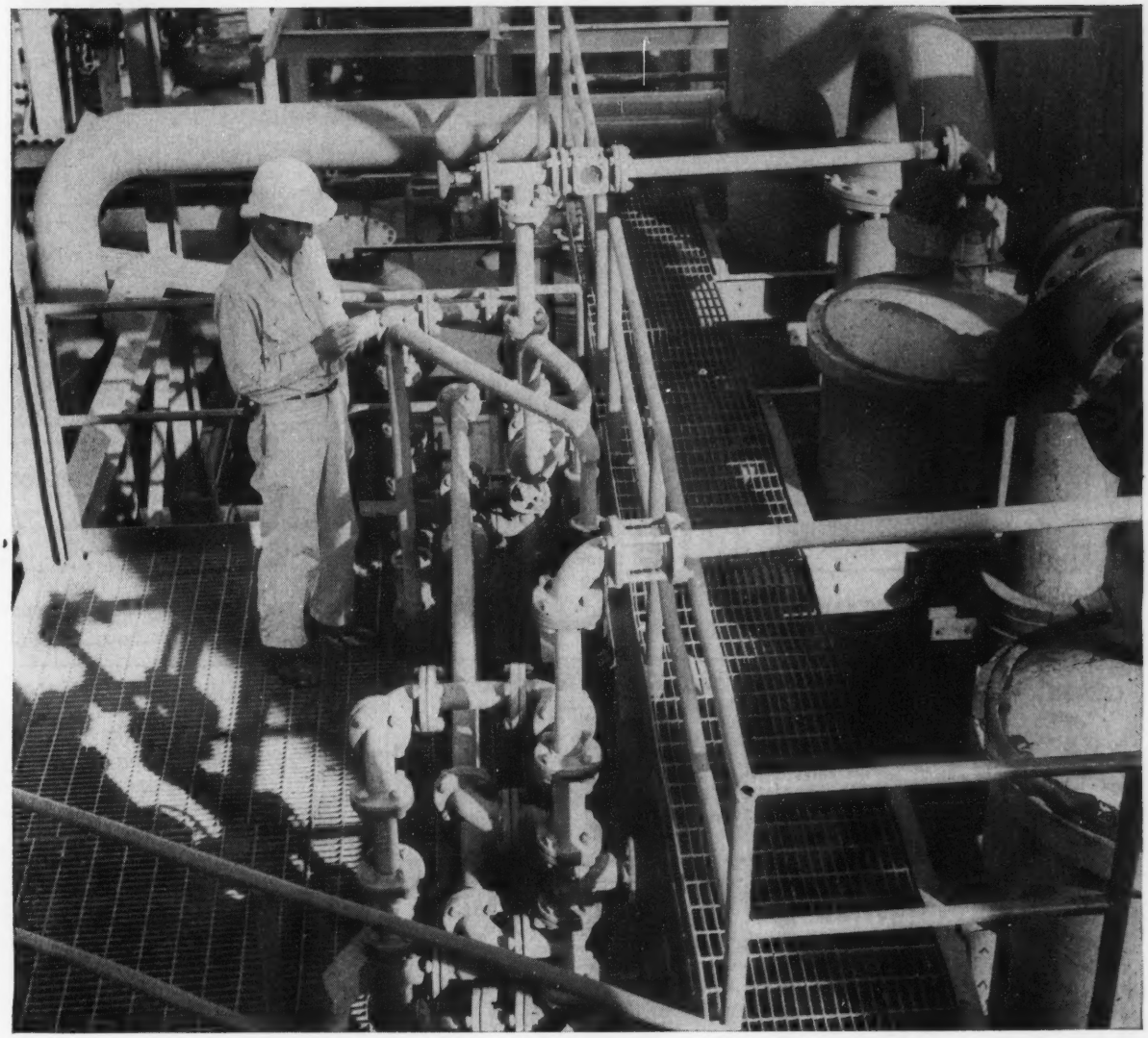
Herbert H. Walther is head of sales offices recently opened by Dowell Division of Dow Chemical Company at 900 Wilshire Blvd., Los Angeles, Cal., to provide chemical cleaning services.

•

E. T. Walton has been appointed director of metallurgy for Crucible Steel Company of America, Oliver Bldg., Pittsburgh 22, Pa.

(Continued on Page 100)

DOW | SARAN LINED PIPE



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MEN in the NEWS

(Continued From Page 98)

Don Westbo, NACE member, has been named manager of the rectifier division of Holcombe Company, Shreveport, La.

•

F. W. Wolchek, 293 Dushane Dr., Kenmore 23, N. Y., is a new sales represenative for Wisconsin Protective Coating Co., to cover western New York State.

•

Richard E. Boller, Jr., has been appointed to the new post of general sales manager for Alloy Steel Products Company, Linden, N. J.

•

Howard F. Modjeski has been added to the engineering staff at Midwest Technical Service, Downers Grove, Ill.

•

John G. Galloway, NACE member, has been appointed eastern sales manager for Ceilcoate Co., 4832 Ridge Road, Cleveland 9, Ohio. **T. D. Skaggs** is the new southeastern sales manager with headquarters in Birmingham, Ala.

•

George Russell has been promoted to chief engineer at Amchem Products, Inc., Ambler, Pa.

•

Edwin W. Vereeke, NACE member, has been elected president of Heil Process Equipment Corp., Cleveland, Ohio.

•

Six NACE members have been appointed to new sales positions with the Kendall Company and its Polyken Protective Coatings division. They are **Alfred J. Spiry,** international division for Kendall Company; **Donald W. McCabe** as Polyken's assistant merchandise manager in Chicago; **James C. O'Brien** as midwest representative for Polyken;

•

Robert L. Toney as Polyken representative in the southwest; **William F. Lechler** as Polyken representative in the north central region with offices at Kansas City, Mo.; and **Joseph F. Batteer** in the northeast for Polyken.

•

Ben Sloat has been appointed southwest oil field sales engineer for Hagan Chemicals & Controls, Inc., and its division Calgon Company and Bradford Laboratories with headquarters at 327 South College, Tulsa, Okla.

•

W. K. Venatta is the newly appointed manager of the manufacturing department of the Oronite Chemical Company, 200 Bush St., San Francisco 20.

(Continued on Page 101)

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MEN in the NEWS

(Continued From Page 100)

Howard F. Roderick has been named president of the recently organized Miles Chemical Co., 1127 Myrtle St., Elkhart, Ind. The new company is one of four main divisions of Miles Laboratories.

•

David H. Pyle has joined the U. S. Stoneware Co. as sales representative in the Philadelphia territory.

•

Joe L. Thompson will serve as resident manager in Caracas, Venezuela, for the Dowell Division of the Dow Chemical International Limited, S. A. **G. T. Lamberson** is now resident manager in Argentina.

•

Paul E. Kelly has been appointed manager of sales, **Selden E. Doughty** has been appointed manager of technical services, and **Griffin M. Stabler** has been appointed manager of production for the Alloy Tube Division of the Carpenter Steel Co., Union, N. J.

•

Gerald L. Jensen has been appointed field service engineer for the Pacific northwest by A. M. Byers Co., Pittsburgh. His office is at 574 Dexter Horton Bldg., Seattle.

•

William H. Hollen has been named a chemical products field sales engineer by National Carbon Co., division of Union Carbide Corp. He will make his headquarters in St. Louis.

•

Howard D. Hartough has been elected president of the Chemical Products Division of Chemetron Corp. For the present he will make his headquarters in Louisville.

•

James P. Haas has been appointed manager of research and development for the Metal Products Division of Koppers Co., Inc., Baltimore 3, Md.

•

Joseph H. Anderer has been named assistant manager of the Applications Research and Development Section of American Viscose Corporation's Fibers Division, 1617 Pennsylvania Blvd., Philadelphia 3.

•

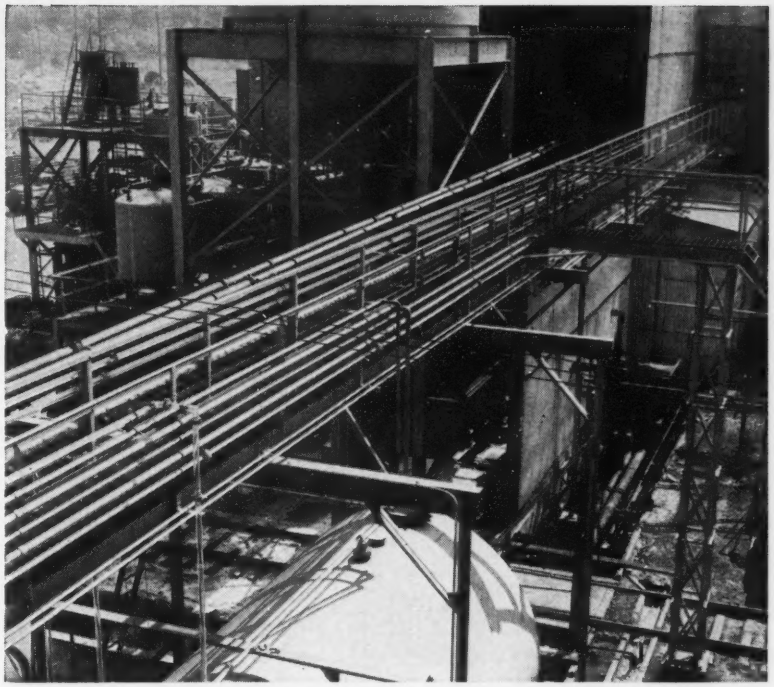
Rupert H. Poetker, corrosion engineer for Sunray Mid-Continent Oil Co., has joined Petrolite Corporation's corrosion research staff at St. Louis. Mr. Poetker is a member of National Association of Corrosion Engineers.

•

George O. Hiers, Baldwin, N. Y., consulting metallurgist and **Beaumont Thomas,** director and vice-president for development and research for the Stebbins Engineering & Manufacturing Co., Watertown, N. Y., were selected to receive awards from the American Society for Testing Materials. The special recognition was planned for the ASTM's 62nd Annual Meeting, in June at Atlantic City. Both men are members of National Association of Corrosion Engineers.

•

J. H. Westbrook, metallurgist, General Electric Research Lab., Schenectady, New York, received the Richard L. Templin Award of the American Society for Testing Materials at the society's June meeting.



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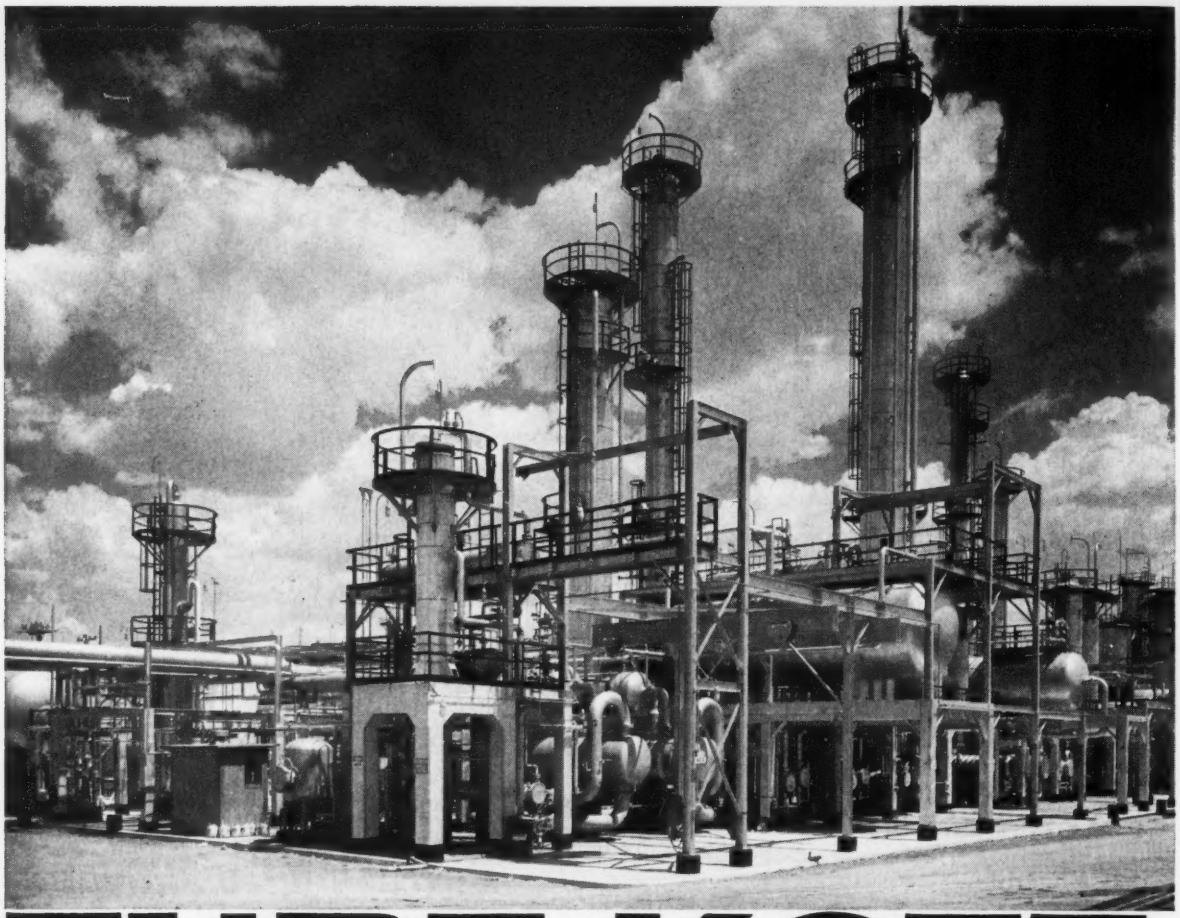

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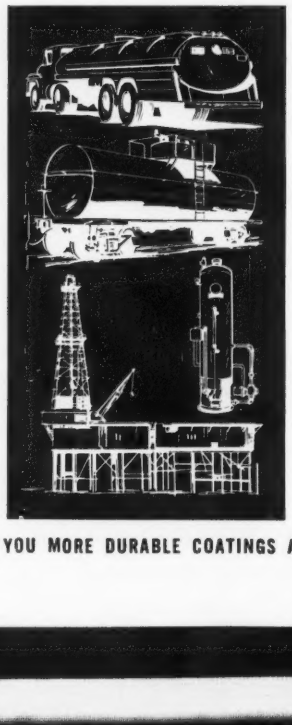

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TECHNICAL TOPICS

Mechanisms and Some Theoretical Aspects of

Stress Corrosion Cracking of Austenitic Stainless Steels*

Abstract

After reviewing briefly the generally accepted causes of stress corrosion cracking of stainless steels, design of heat exchangers intended for use with chloride-containing waters is considered. Conditions causing stress corrosion cracking make tube-side cooling better than shell side, favor designs eliminating stagnation and make mandatory operation resulting in full water boxes. Velocity in excess of 5 fps is recommended.

Insulation containing chlorides should be protected from moisture and water temperatures kept as low as possible. Good aeration is necessary and recirculating waters should contain no chromates or other oxidizing compounds. While pH is not critical, this does not mean that pH in concentration cell anolytes is not important.

Theoretical considerations involved in the stress corrosion cracking phenomenon are considered. Plastic deformation, which results in the accumulation of stresses at barriers along a slip plane, is viewed as a precedent to cracking. Nickel, among alloy constituents, is seen as beneficial in preventing cracking, and the reasons for this are suggested as an avenue of fruitful investigation. The nature of the corrosion phenomenon, involving such complex factors as films, adsorption effects and electrical double layers are mentioned as areas where more study would be rewarding.

Possibility of thermal or electrochemical concentration of chlorides must be designed out, cleaned out or kept out of industrial cooling water systems, the author concludes. 3.5.8

Introduction

WHEN THE stainless steel industry starting its growth 18 years ago, the cracking of a Type 304 thermocouple well containing moist ethyl chloride became the subject of a paper which drew worldwide attention.[1] This cracking of the new corrosion resistant material under no external load and in a mildly corrosive environment was a surprising development.

Although a completely satisfactory theory for stress corrosion cracking has not been established, some useful facts and encouraging trends are emerging from tests and experiments:

1. Cracks are characteristically transcrystalline and display multiple branching as they progress, as shown in Figure 1. Intergranular cracking may result from sensitization to intergranular corrosion by carbide precipitation and stress. This form of stress corrosion cracking has obvious causes and cures. It will not be considered here except to note that it may alter transcrystalline cracking under appropriate electrochemical conditions, as will be discussed later.

2. There is no minimum threshold stress below which stress corrosion cracking will not occur.[2,3,4]

3. The environment may be only mildly corrosive and usually is characterized by the presence of acid chlorides. (As will be seen later, electrochemical action can develop a locally acidic condition and chloride concentration in a netural or even alkaline environment).

4. Cracking is favored by high temperatures at or near the boiling point of the solution involved.

5. The phenomenon is electrochemical and can be prevented or stopped by cathodic protection.[3] Oxygen or some other depolarizing agent appears necessary for cracking to start and progress.

6. There is no maximum pH or minimum chloride concentration necessary for stress corrosion cracking. Indeed, seemingly innocuous traces of chloride ion in the order of several parts per million have been concentrated by evaporation or electrochemical action so that they have caused cracking. This has occurred even in the high purity water used in certain atomic installations. Mere tap water dripping on a hot stainless surface will cause cracking.

7. Tensile stresses cause cracking in an appropriate environment. Compressive stresses do not. The case for shear does not appear to have been investigated.

8. Path of the cracks is more or less normal to the axis of the major tensile stresses in the system. At first glance, it appears there is little relation to metallographic features such as orientation, slip planes, twins, etc. On the other hand, there now appears much reason to associate transcrystalline stress corrosion cracking with the dislocations created by plastic flow.[4,5]

9. Minor variations in composition, deoxidation practice, the presence or absence of titanium, columbium, molybdenum or copper have little effect.

These few facts offer little foothold for remedial action or fruitful research, yet much can be done in both areas. This paper explores some of these avenues.

Heat Exchanger Design

In heat exchange equipment and condensers employing tube side cooling with chloride containing waters, much cracking has been caused by concentration of salines in the crevice between tube and tube sheet. Such cracking can be eliminated by seal welding the tube ends. A neat, smooth and streamlined weld can be obtained with proper joint preparation and inert gas welding. This method is used to some extent but merits wider recognition and application.

(Continued on Page 106)

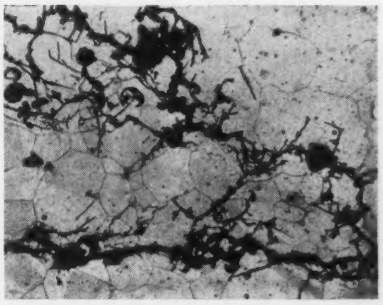


Figure 1—Stress corrosion cracking in a pipe carrying oxygen and steam. Thermal cycling with alternate condensation and evaporation caused concentration of entrained solids. Conductivity of steam condensate ranged from 0.6 to 6 micromhos.

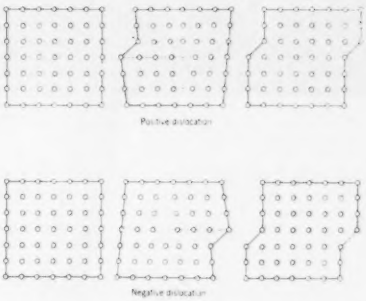


Figure 2—A simple concept of an edge dislocation. (By permission from "Physics of Metal" by F. Seitz. Copyright, 1943. McGraw-Hill Book Co.)

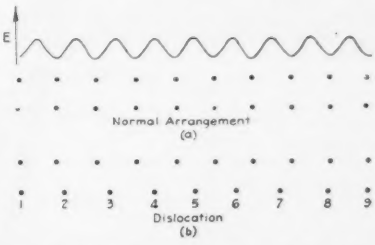
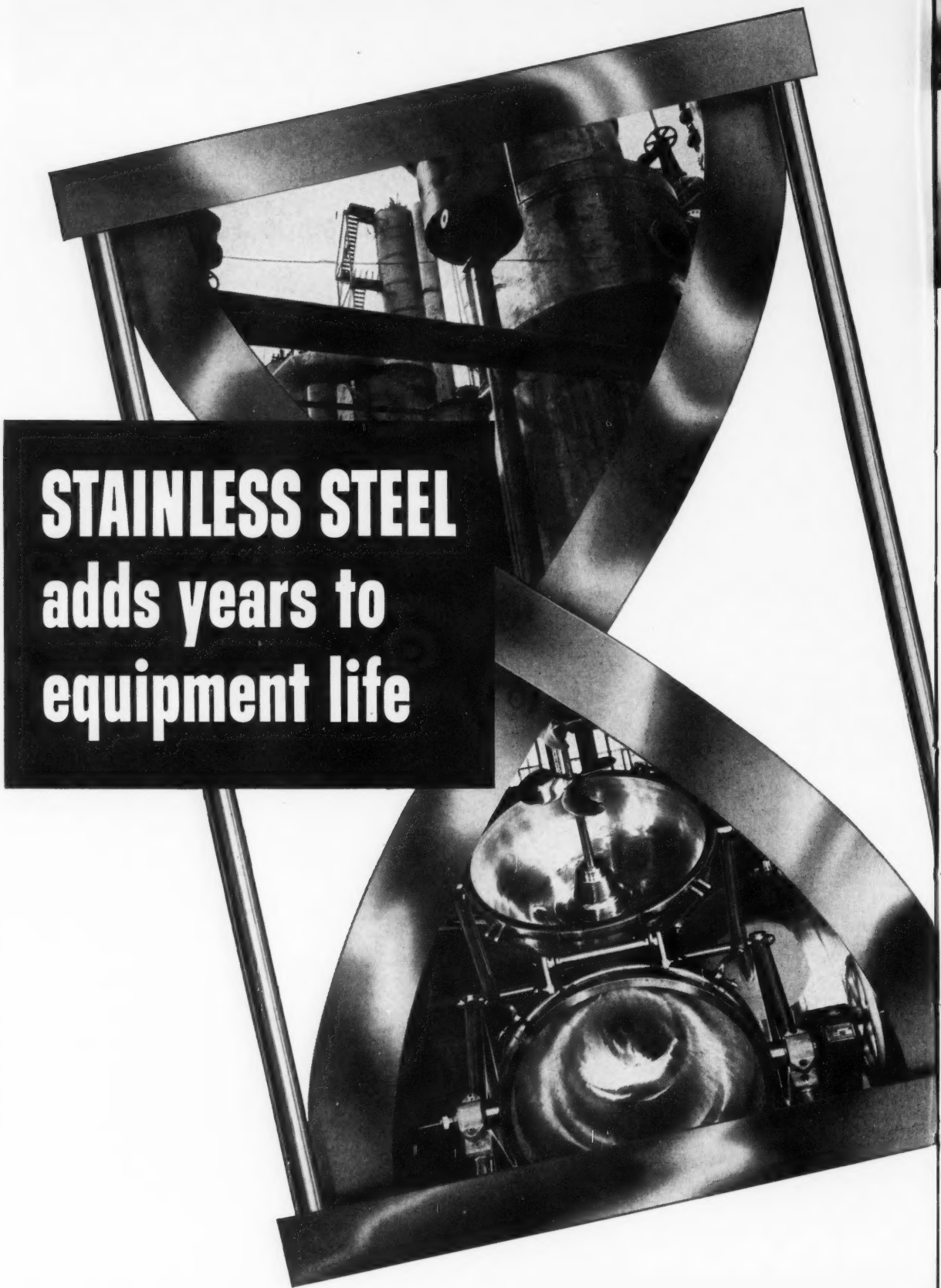


Figure 3—Schematic representation of the fact that a dislocation moves easily. Upper curve represents potential energy of an atom in a given plane arising from atoms in the plane above it. (By permission from "Physics of Metal" by F. Seitz. Copyright, 1943. McGraw-Hill Book Co.)

★ Revision of a paper titled "Stress Corrosion Cracking of the Austenitic Stainless Steels" by W. B. Brooks, Dow Chemical Co., Freeport, Texas, submitted for publication August 25, 1958.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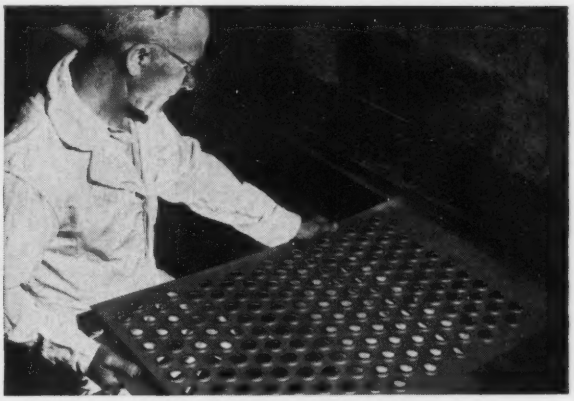

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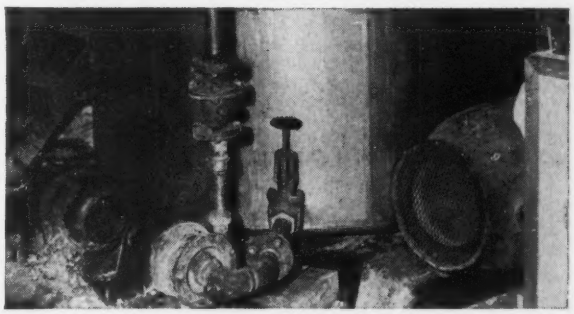

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Stress Corrosion—

(Continued From Page 103)

Shell side cooling, however attractive it may be to some chemical engineers, is fundamentally bad design with stainless steel. The chloride concentration between tube and tube sheet cannot be prevented by seal welding. Steaming and chloride concentration also will occur between tubes and baffles or supports. Moreover, the shell side will have some stagnant zones. Stainless steels thrive on velocity, turbulence and aeration. Conversely, stagnation promotes pitting, and conditions which promote pitting also may produce cracking.

Chloride concentration and cracking have occurred in vapor pockets. Heat exchange equipment of both types should be designed to avoid these pockets as far as possible. With tube side cooling, chloride concentration and cracking can be avoided by providing an overhead bypass vent between water boxes and by operating the equipment will full water boxes. It will be helpful to omit or plug the customary one or two top rows of tubes which might be partially or intermittently filled. With shell side cooling, vapor pockets are difficult to avoid.

A minimum water velocity in the tubes of 5 fps should be maintained to avoid deposition of entrained solids which can lead to concentration cell corrosion and subsequently to cracking. Deposition of entrained solids in regions of low velocity or stagnation is another potent reason to shun shell side cooling.

By changing to tube side cooling, one chemical company eliminated repeated cracking troubles experienced with shell side cooling involving a chloride containing water.

Hazards From Insulation

Magnesium oxide, calcium silicate, glass fiber and foam glass contain enough leachable chlorides to cause cracking where the insulation is exposed to the weather, wet steam or drips from leaky valves, etc. Reaching the hot metal surface by capillary action, water evaporates and deposits its burden of dissolved solids. DuPont has reported 44 cases of this kind.[6] Chloride content of the insulating materials which caused cracking ranged from .01 to .51 percent. Metal temperature limits for this phenomenon have not been established. The phenomenon can be reproduced experimentally at 100 C and probably will occur at temperatures to 170 C.

Factor of Temperature

Stress corrosion cracking is highly temperature dependent. DuPont has reported no cases of cracking observed below 50 C.[7] Cracking has been reported as high as 260 C with equipment under pressure and the corrosion products indicating that condensate was present.

On the other hand, cracking has occurred at ambient temperatures. Types 302 and 316 wire rope exposed to airborne magnesium chloride have cracked. Wire rope contains high internal stresses and capacity for concentrating salts. Horizontal runs of Type 304 instrument tubing have cracked in a similar environment. Type 302 wire rope has cracked in an unpolluted marine atmosphere on the Florida Coast.

The greatest frequency of cracking is in the 80 to 110 C range, thus occuring at the boiling point of water and underlining the concentration of chlorides by thermal means.

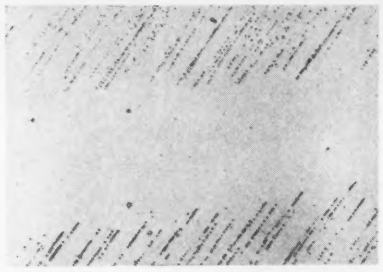

Figure 4—Etch pits of dislocations in bent silicon ferrite. (W. R. Hibbard, Jr., and C. G. Dunn. Study of Edge Dislocations in Bent Silicon Ferrite Single Crystals. Acta Metallurgica, 4, 308, 1956.)

Another effect of temperature is the formation of scale from mineral bearing waters in contact with hot stainless surfaces. The scale sets up a concentration cell which makes possible the electrochemical concentration of chlorides.

Reaction rates and ionic mobilities increase with temperature. Surface tension decreases with temperature, thus increasing film height on surfaces in vapor pockets and facilitating the entry of chlorides into the pits, crevices and cracks, a process which is painfully familiar.

Aeration Is Important

The importance of aeration is confirmed by well established theoretical considerations and various investigations. On the other hand, the low degree of aeration developed by free boiling or the low pressures existing in some condensers are not enough to confer immunity. Other depolarizers obviously would have an accelerating effect, and it would seem that inhibiting systems in recirculated waters should be free of chromates and other oxidizing compounds.

Function of Velocity

Velocity also is important. Again the case for tubeside cooling is strengthened. There is a high incidence of cracking in static or low velocity conditions (under 5 fps) as compared to those where the velocity exceeds 5 fps. This is consistent with the established tendency of the stainless steels to develop pitting in stagnant environments. Even more important than velocity are crevices, rust and scale deposits from mineral bearing waters and stagnant pockets. Although favorable, high velocities do not confer immunity. One case has been reported at 60 fps.

pH is Not Critical

The pH of the environment is important but not critical. Cracking is encountered most frequently in mildly acid environments containing a high concentration of chlorides, yet cracking has occurred in soda ash and 15 percent caustic solutions containing chlorides. Many cases have occurred in essentially neutral waters. These cases are believed to involve the electrochemical concentration of chlorides in the anolyte of concentration cells. Concentration cells are formed in crevices, under deposits, in corrosion product from iron contamination and in weld splatter, etc. The anolyte is strongly acid as a consequence of the hydrolysis of ferrous chloride. The pH of the anolyte may be from 2.5 to 3. Renshaw has reported the development of cracking from a pit.[8]

Though cracking does ocur in alkaline environments, it is less frequent, as might be expected. As pH increases above 7, the potential of the passive areas move in the less noble direction and thus decreases anodic current density, the anode potential being but little changed.

When the pH is sufficiently low to promote more or less general attack, the anodic current density on any tender spots is apparently too low to cause cracking.

Influence of Other Halogens

The statement is made occasionally that halogens cause cracking, without qualification as to which ones are worse than others. Doubtlessly, the almost universal presence of the chloride ion is responsible for its prominence in this phenomenon. The fluoride ion also can cause cracking. This provides ample justification for thorough removal of welding slags and soldering or brazing fluxes which contain fluorides. There are some indications that anion size may play a role. For example, cracking does not occur with sulfates under conditions of pH, temperature and stress which will cause cracking with chlorides. Authentic cases with bromides and iodides free of chlorides are rarely found.

Relation to Intergranular Corrosion

Many cases of stress corrosion cracking have been caused by intergranular corrosion stemming from carbide precipitation. These cases have obvious causes and cures. There have been a few cases[8] where the intergranular attack or cracking—it is difficult to draw the line, with stress present—has altered to transgranular cracking. The common opinion concerning this change relies upon an intergranular crack meeting a grain boundary at almost 90 degrees. Perhaps the resulting stress concentration could crack the grain, but the writer prefers to view this as a form of concentration cell. Some believe that transgranular stress corrosion cracking occurs only in an environment capable of causing pitting, a form of concentration cell.

Some Theoretical Considerations

Role of Plastic Deformation

Crystal growth and plastic deformation generate lattice defects called dislocations. Figure 2 illustrates a simple concept of one type of dislocation. Plastic flow occurs by the migration of dislocations. This explains why metals have only a small fraction of their theoretical strength. This is illustrated in Figure 3.

There are several aspects of dislocations which concern corrosion and stress corrosion cracking. As shown in Figure 2 the dislocation is a region of high energy as compared to any point in the regular lattice at the left. The dislocation is corrosion sensitive. Etch pits developed under certain conditions are the sites of dislocations. These etch pits are illustrated in a bent sheet of 4 percent silicon-iron shown in Figure 4. Engineers will note their absence at the neutral axis.

Dislocations interfere with each other. This is work hardening. Perhaps there is some significance in the unparalleled susceptibility of the austenitic stainless steels to work hardening and their susceptibility to stress corrosion cracking. Stress necessary to move a dislocation is a good definition of yield point. The

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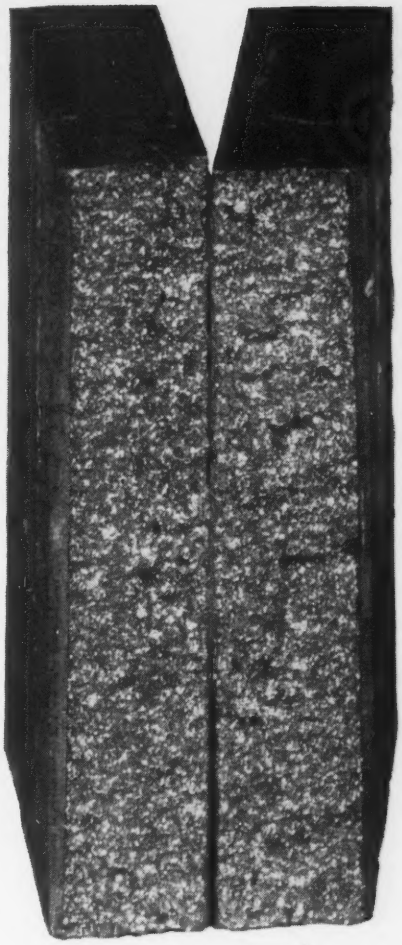

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Stress Corrosion—

(Continued From Page 106)

small interstitial atoms, carbon and nitrogen collect in and around dislocations and pin them, thus causing the phenomenon of the yield point in mild steel. When cold work forces the dislocations to move away from their pinning clouds of carbon and nitrogen atoms, the yield point disappears. As diffusion permits the carbon and nitrogen atoms to collect again around dislocations, the yield point returns. Similarly, if carbon and nitrogen are quantitatively removed from iron by treatment in wet hydrogen, it has no yield point.

H. H. Uhlig at Massachusetts Institute of Technology has found that an alloy containing 18 percent Cr and 20 percent Ni with very low carbon and nitrogen is highly resistant to stress corrosion cracking.[4] There may be a connection between this alloy's charateristics and the phenomenon of pinned dislocations.

Role of Hydrogen

Hydrogen may play a role in stress corrosion cracking. The cause of the hydrogen embrittlement of cold worked low carbon steel is the concentration of hydrogen in dislocations and also is the cause of the so-called stress corrosion cracking of hardenable low alloy and stainless steels subject to H_2S corrosion in oil production and refining.

Figure 5—Three possible diffusion mechanisms. (a) Interchange by rotation about a midway point, forcing neighboring atoms apart. (b) Migration through interstitial sites. (c) Atoms exchange position with vacant lattice sites. (By permission from "Physics of Metal" by F. Seitz. Copyright, 1943. McGraw-Hill Book Co.)

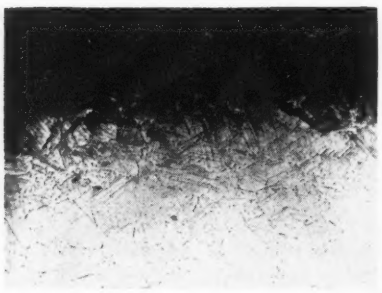

Figure 6—Diffusion of carbon along slip bands in 18-8 oil refinery cracking furnace tube.

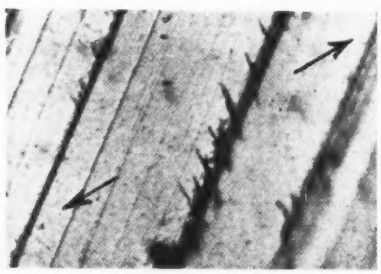

Figure 7—Cracks nucleated in slip clusters and growing normal to the axis of tensile stress.[5]

Hydrogen evolution has been observed at and near the head of advancing stress corrosion cracks in magnesium. Solubility of hydrogen in austenitic steel is high, however, so its role is not clear.

Figure 5 shows several possible diffusion mechanisms. Activation energy determinations show that the vacancy exchange mechanism illustrated in Part C of the figure is the most likely. A slip band contains many vacancies and dislocations. Figure 6 shows the precipitation of carbon along slip bands in an 18—8 cracking furnace tube from an oil refinery. All this is by way of showing the disorganization and chemical activity which exists in a slip band. W. D. Robertson[6] (Figure 7) has concluded that plastic flow and the resulting slip bands provide what he calls the chemical activation necessary to nucleate cracks. His metallographic evidence is convincing. His work has been with the system copper-gold chosen for its simplicity; it also crystallizes in the face centered cubic system. Slip may be a condition precedent in the transcrystalline stress corrosion cracking of all alloys.

A further development of the dislocation theory may possibly be applied to stress corrosion cracking. It has been held theoretically and shown metallographically (Figure 8) that dislocations moving along a slip plane pile up against barriers such as grain boundaries. Stroh[9] has analyzed the stress at the head of a pile-up and has shown that it is of the same order as the theoretical cleavage strength—i.e. about 10^3 greater than the so-called tensile strength. The stress is proportional to the number of dislocations in the pile-up which in turn is proportional to the grain size. This has been nicely related to the observed variation in tensile strength with grain size. These micro stresses provide for the nucleation of the Griffiths cracks required by cleavage theory and perhaps for introduction of voids in stress rupture and high incidence of intergranular stress corrosion cracking in many alloy systems.

In connection with transgranular stress corrosion cracking, pile-ups also occur within the grain. Such high stresses from the basis for a more satisfactory development of an electrochemical theory of stress than has been possible, heretofore.

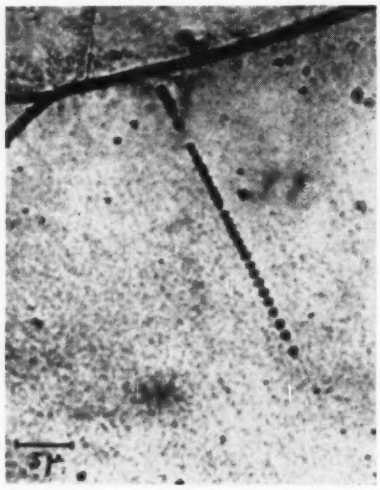

Figure 8—Dislocation pile-up in alpha brass.[13]

Influence of Alloy Composition

All the 300 series alloys crack. Variations in minor elements, deoxidation practice, addition of columbium, titanium, molybdenum, etc., have little or no effect. This is not strictly true, however, because molybdenum, for example, may substantially increase the stress required in some cases, as shown in Figure 9.

Also, there seems to be a trend to lower susceptibility with increasing nickel content because high susceptibility has been noted in low nickel alloys. British investigators have coined the term "quasi-martensite." On work hardening, the lean chromium nickel iron alloys become magnetic, indicating decomposition of the austenite. Indeed there seems little need for the term "quasi." Martensite is formed. Formation of a new phase inevitably introduces micro stresses. The term "micro" is used not to indicate low stresses but rather stresses created by the differences in density, elastic modulus and thermal expansion of micro constituents. In severely cold worked Type 301, these stress variations are sufficient to cause cracking in the absence of any corrosive environment other than slightly humid air if that can be considered corrosive to a stainless steel. Unquestionably, these differences contribute to stress corrosion cracking in the 18—8 alloys. The quasi-martensite theory is not applicable, however, to higher nickel alloys in which thus far it has been impossible to detect evidence of ferrite or martensite.

Although some higher nickel alloys crack, there is a direct relationship between increasing nickel content and time of failure.[10] (Figure 10) The resistance of Uhlig's experimental alloy containing 18 Cr and 20 Ni with low carbon and nitrogen has been mentioned. Duriment 20 type alloy containing 25 to 30 nickel with additions of copper and molybdenum is significantly more resistant, Type 330, 15 Cr Ni, has proved more resistant in some cases. When the nickel content exceeds 40, susceptibility to cracking largely disappears. Inconel is immune. Theoretical implications of the benefits of higher nickel content do not appear to have been explored. Because there is presently an

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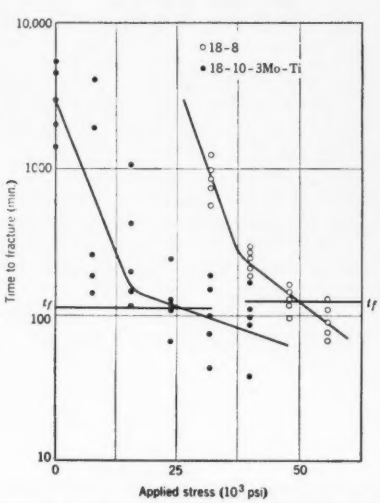

Figure 9—Stress vs cracking time of wires in $MgCl_2$.[2]

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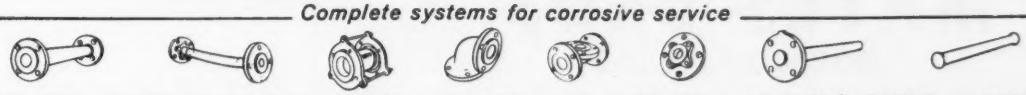

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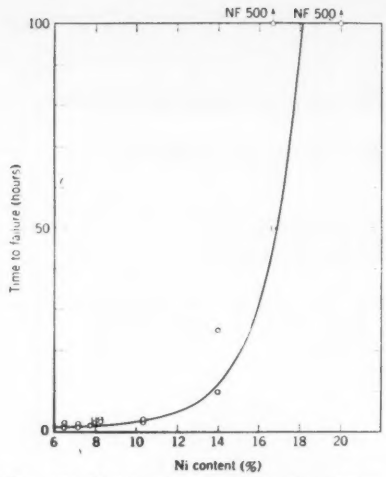

Figure 10—Nickel content vs cracking time. (J Iron and Steel Inst, 173, 140-146 (1953).

Stress Corrosion–

(Continued From Page 108)

abundance of nickel, this would seem to be a fruitful avenue of both theoretical and practical approach.

What of Film Mechanism?

Another area which commands attention is the matter of films which are significant generally in corrosion. Too often, a corrosion system is viewed as a metal in contact with its environment. This is true only momentarily where there is abrasion or crack formation. The system is in fact metal-**film**-environment, and the system is complicated further by absorption phenomena and the electrical double layer of the electrochemists.

Logan at the Bureau of Standards, especially, has considered the problem from the standpoint of film rupture.[11] The great importance of tension as opposed to compression underlines the significance of this aspect. On the other hand, it is difficult to visualize films on stainless steels as brittle. Some work at DuPoint[12] has shown that these films are essentially hydrogels of variable water content and of a composition not predictable from that of the substrate alloy.

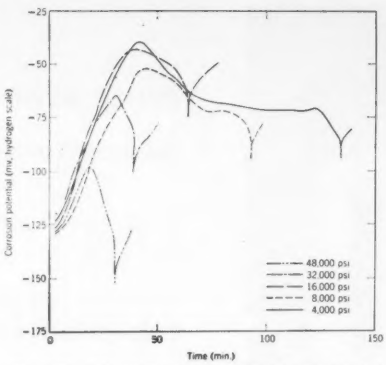

Figure 11—Potential vs time of 18-8 wires in $MgCl_2$.[3]

The fine work of Hoar and Hines also is illuminating with respect to film behavior in chloride environments. Figure 11 illustrates a highly significant feature of their work. In the first few minutes, the potential becomes less noble, suggesting rapid penetration of the film at sensitive spots by the corrodent. (This occurs with or without applied stress). Perhaps next, precipitation of hydroxides then takes over and there is a period of film repair. Oxygen absorption also could account for this rise. The potential becomes more noble and passes through a maximum. Activation of metal at slip bands, if that is what it is, then takes over; the potential gets less noble again, and cracking ensues. Film formation in the crack may be seen in the rapid recovery of the potential. Cracking occurs at a stress as low as 4000 psi. Hoar and Hines were working with solution quenched wires which probably contained internal stress of greater magnitude.

Some Conclusions

No industrially available cooling water may be trusted to provide freedom from stress corrosion cracking on stainless steel if possibility exists for the thermal or electrochemical concentration of chlorides. These must be either designed out, cleaned out or kept out.

Heat exchanger design should be based on tube-side cooling with co-current flow and seal welded tube ends. Design and operation should eliminate vapor pockets. Cooling capacity and velocity should be great enough to prevent deposition of entrained solids, scale formation and flashing. Because the cracking process is temperature dependent, generous cooling capacity, if economics permit, will be rewarding.

Post fabrication cleaning to remove weld scale and splatter, iron contamination and other foreign matter is recommended.

Inorganic insulating materials must be protected against moisture.

Nickel-chromium-iron-molybdenum-copper alloys are usefully resistant in some cases and their resistance increases with increasing nickel.

Carbon and nitrogen may play a hitherto unsuspected role and plastic flow rather than some minimum stress level may be a condition precedent.

Some methods have been outlined for avoiding stress corrosion cracking and some areas indicated in which fundamental research may be rewarding. In connection with the latter, the Corrosion Research Council of The Engineering Foundation is sponsoring research in this field.

References

1. J. C. Hodge and J. L. Miller. Stress Corrosion Cracking of the Austenitic Chromium-Nickel Stainless Steels. *Trans Amer Soc Metals*, **28** 25-82 (1940).
2. Julius H. Hardwood. Influence of Stress on Corrosion. *Corrosion*, **6**, (Part 1) 249 (1950) August; (Part 2) 290 (1950) September.
3. T. P. Hoar and J. G. Hines. Stress Corrosion Cracking of Austenitic Stainless Steels. *Iron and Steel Inst*, **182**, Part 2, 124-143 (1956) Feb.
4. H. H. Uhlig and A. White. Austenitic Cr-Ni-Fe Alloys Resistant to Stress Corrosion Cracking in Magnesium Chloride. *Acta Metallurgica*, **5**, 473 (1957).
5. R. Bakish and W. D. Robertson. Structure-Dependent Chemical Reaction and Nucleation of Fracture Cu_3Au Single Crystals. *Acta Metallurgica*, **4**, 342 (1956).
6. C. Edeleanu. *J. Inst Metals*, **80**, 187-191 (1952).
7. J. A. Collins. Effect of Design Fabrication and Installation on the Performance of Stainless Steel Equipment. *Corrosion*, **11**, 11t (1955).
8. W. G. Renshaw. Nature of Stress Corrosion Cracking of Stainless Steels When Other Types of Corrosion Are Present. *Corrosion*, **12**, 477t (1956).
9. A. N. Stroh. Formation of Cracks in Plastic Flow. *Proc Royal Soc*, A232, 548 (1955).
10. C. Edeleanu. Stress Corrosion Cracking and Embrittlement. John Wiley and Sons, New York City, 1956, page 129.
11. H. L. Logan. *J Research NBS*, **48**, 99 (1952).
12. Thor N. Rhodin. Relation of Thin Films to Corrosion. *Corrosion*, **12**, 465t (1956).
13. P. A. Jacquet. Recherches Experimentals Sur la Microstructure de la Solution Sodile Cuivre-Zinc 65-35 Polly-crystalline Tres Faillement Deformee par Traction et sur Son Evolution au Recuit Entre 200 et 600 C. *Acta Metallurgica*, **2**, 752 (1954).
14. C. Edeleanu. *J Inst Metals*, **80**, 173, 140-146 (1953).

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NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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Methods of Installing

Cathodic Protection Anodes For Offshore Structures*

Abstract

New methods of installing anodes in cathodic protection systems for offshore drilling structures are given: anodes mounted on steel pipe, anodes connected to a heavy cable that is buried in muddy bottom diagonally from structure's corners and anodes installed in plastic tubing for protection from wave action and floating debris and for easy examination.

Also briefly discusses operating of graphite anodes above the manufacturers' recommended current density so that a minimum number of anodes in combination with a rectifier can be used to protect a structure. 5.2.1

Introduction

DIFFICULTY OF installation and the liability to storm damage of anodes suspended on steel cable to give cathodic protection to offshore oil well drilling structures have led to the study of better methods of anode installation.

One method is to mount 50-pound magnesium anodes on a steel pipe. The anodes have a steel pipe core which is coupled to the 3-inch mounting pipe by the use of unions. The 3-inch pipe is set vertically, the top being clamped to the structure and the bottom stuck in the muddy bottom.

Five years' experience has shown that anodes do not have to be suspended within the framework of the platform. Many systems now are installed with anodes connected to a heavy cable which is buried in the muddy bottom diagonally from the structure corners. Only one point of connection is necessary for a string of five or more anodes. Anode current output is found to be better than 50 percent of that for a single suspended anode, which is satisfactory inasmuch as it is generally necessary to reduce by the resistance method the output of the single anode string by about 50 percent. Original installation and replacement of anodes by this method are simple and less expensive than other methods.

Rectifiers as a means of providing protective current to offshore structures have been used for the past few years. Special treated graphite anodes have given good service as the ground bed, being set apart from that structure.

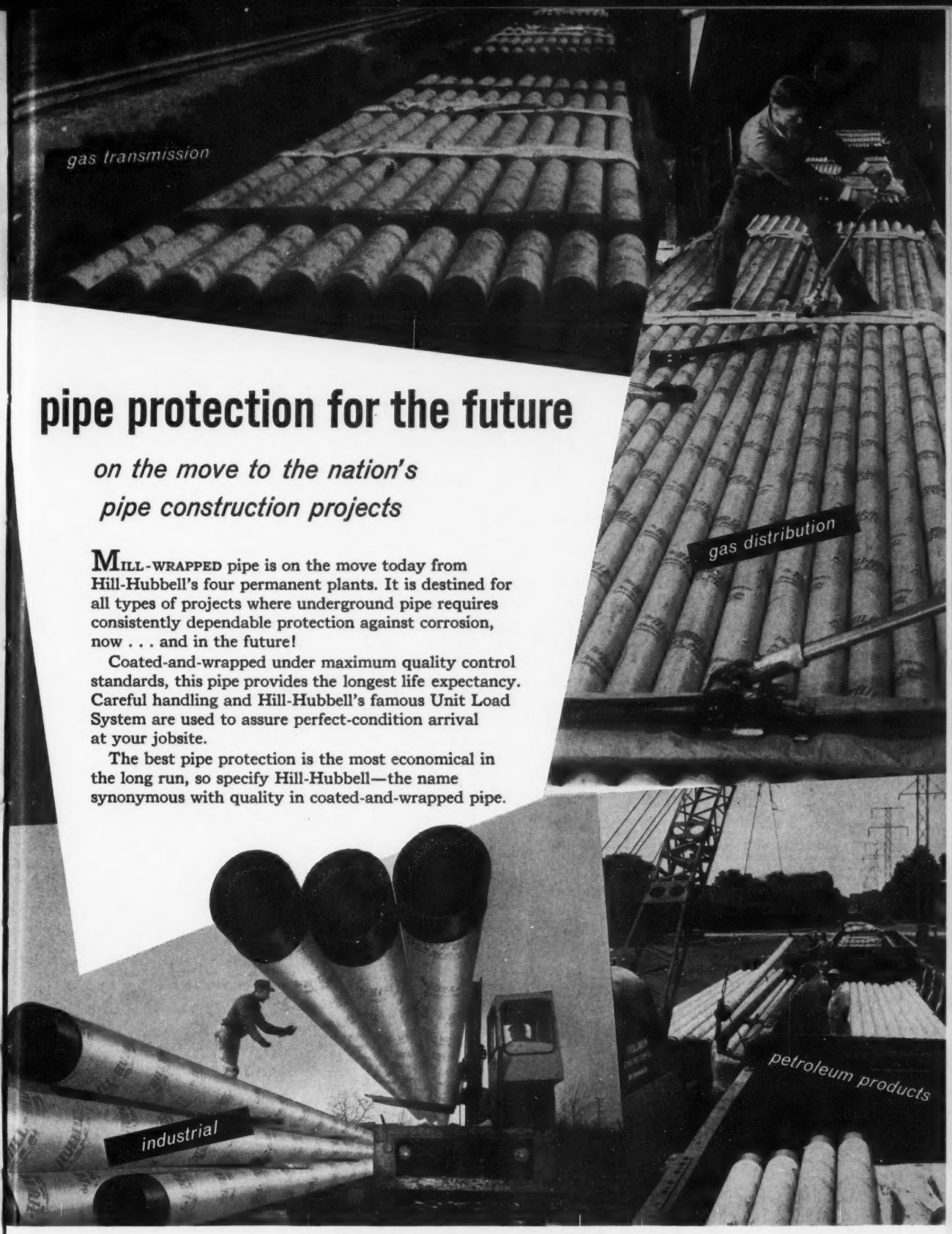
Another common method of mounting the 3 by 60-inch graphite anodes is to install them in a 4-inch diameter plastic tubing which has ½-inch diameter holes drilled at 2-inch spacings (see Figure 1). Current flows from the anode through the holes and thence to the steel structure. The plastic tubing must be mounted so as to suffer the least damage from wave action and floating debris. Anodes mounted this way can be retrieved easily for examination.

Experience has shown that graphite anodes may be operated at many times the manufacturers' recommended current density. Some 3 by 60-inch anodes are operated as high as 25 amperes of current with considerable anode body remaining after two years' operation. Thus, by the combination of a rectifier and a minimum number of graphite anodes, a structure may be protected readily. One graphite anode at 15 amperes can provide the protection of five magnesium anode strings of 3 amperes each. Original installation cost and replacement cost are thereby reduced. This system's use is contingent on the availability of a-c power.

Cathodic protection costs for the submerged portions of offshore structures vary from 3 cents to 6 cents per square foot of protected surface per year. Effectiveness of present methods in preventing corrosion is proved because, compared to the total cost of maintenance, the cost of cathodic protection is small. Improvements and cost reductions in the future will depend considerably on development of effective underwater coatings and possibly simpler methods of anode suspensions. Zinc and aluminum have promise, and wind driven d-c generators are being tested on some locations.

Figure 1—Method of mounting graphite anodes in a plastic tube.

★ Extracted from a paper titled "Cathodic Protection of Offshore Platforms" by Wayne A. Johnson and James T. Condry, presented at a meeting of the 15th Annual Conference, National Association of Corrosion Engineers, Chicago, Ill., March 16-20, 1959.



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NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas

Western Region Conference will be held September 29-October 1 at the Bakersfield Inn, Bakersfield, Cal.

Abstract

Describes modifications on a carpenter's electric routing tool to make an instrument that can measure sub-surface corrosion of aluminum alloys in the field. 2.4.2

RAPID MEASUREMENT in the field of sub-surface corrosion (pitting or intergranular attack) of aluminum alloys can be done by modifying a carpenter's electric routing tool. The router is fitted with a new base which has a fine thread to permit advancement of the end mill cutter in small measurable increments. A hole is drilled in the aluminum alloy structure until sound metal is encountered. An accurate reading can be taken in a few minutes.

This method can also be used to advantage in the laboratory because of the speed with which results are available. It is much faster than metallographic sectioning, yet equally accurate.

Modifications described were made on a Stanley router, model H-39-B. The base, which is threaded onto the motor housing, was removed and replaced with the base shown in Figures 1 and 2. This is bolted to three tapped holes on the motor housing bottom. With 40 threads per inch, one full revolution of the base advances the cutter 25 mils. The upper face of the base was marked with radial lines at one mil spacing. A pointer was fixed to the motor housing to move around the base scale as the tool was advanced, thus giving accurate measurement of the depth of cut (the spacing between adjacent one mil markings is 5/16 inch). The base was faced with a layer of micarta with inset machine screws which permitted a flashlight tester to be connected between the motor housing and the specimen surface.

In operation, the router is rotated to advance the cutter until its face just makes contact with the surface. The position of the pointer on the base scale is then read. The tool is advanced the desired increment, the set screw tightened and the cut made. The base of the hole is inspected visually. Successive increments of cut are taken until sound metal is encountered. Depth of cut is read from the new position of the pointer on the base scale and can be checked with a pit depth micrometer. Experience has proved the device sufficiently accurate.

This method is fast, accurate, nondestructive (only corroded metal is removed) and can be used in the field. Thus far the device has been tried only on aluminum alloys. However, the principle should be applicable to other metals although a different motor speed (other than 22,000 rpm on the router) may be required.

★ Revision of a paper titled "A Rapid Method for the Measurement of Subsurface Corrosion on Aluminum Alloys in the Field" by Hugh P. Godard, Aluminium Laboratories Limited, Kingston, Ont., Canada, submitted October 13, 1958, for publication.

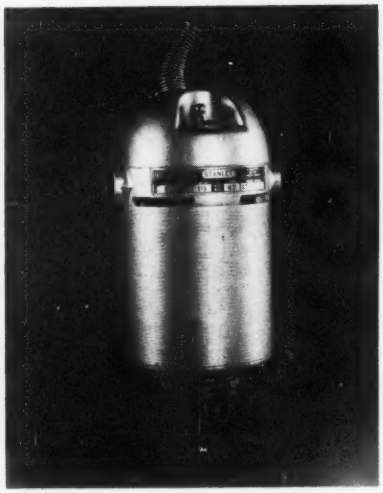

Figure 1—Modifications made on a carpenter's electric routing tool for rapid measurement of subsurface corrosion of aluminum alloys.

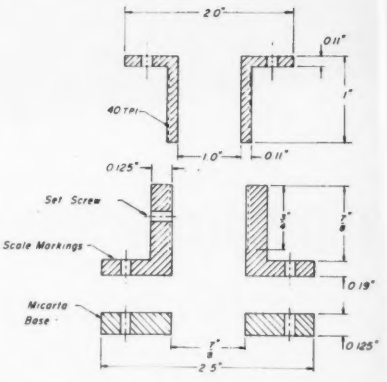

Figure 2—Sketch of modified base which was threaded onto the motor housing.

Technical Topics Scheduled for October

New Bonding Process Gives Added Versatility to Cladding, by R. A. Davis

Potentialities and Applications of Special Corrosion Resistant Refractories, by Roy W. Brown and H. G. Noble

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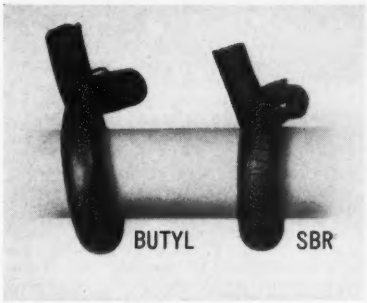

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Abstract

Case histories are given of differential aeration corrosion in lead sheathed telephone cables when water is entrapped because of dips in the conduit. Solution of each case is given with illustrations. Cathodic protection of the cables is also discussed and the problems presented in obtaining sufficient current without causing interference to foreign substructures near the cables. 3.6.2

Case Histories of

Differential Aeration Corrosion In Underground Telephone Cables★

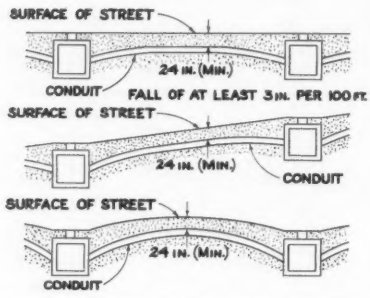

Figure 1—Schematic drawing showing how conduit system is drained of water.

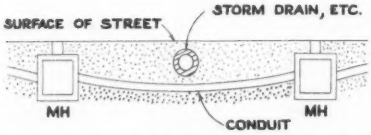

Figure 2—A dip placed in the telephone conduit system because of other foreign substructures above.

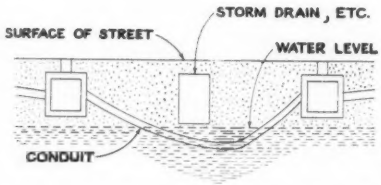

Figure 3—Telephone conduit system with a dip partially submerged in the water table.

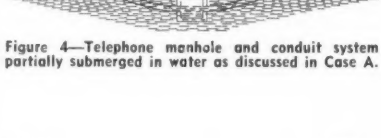

Figure 4—Telephone manhole and conduit system partially submerged in water as discussed in Case A.

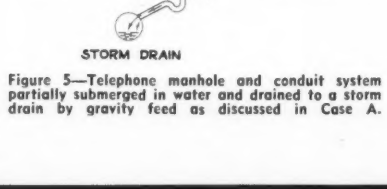

Figure 5—Telephone manhole and conduit system partially submerged in water and drained to a storm drain by gravity feed as discussed in Case A.

Introduction

IN SOUTHERN California a great amount of water flows in subterranean rivers. Occasionally, it is necessary to place telephone underground conduit through these subterranean streams. This has created a corrosion problem due to differential aeration.

Some of the corrosion problems that have been caused by this partial submergence and measures used to correct the problems are discussed in this paper. The question of nullifying voltages created by these local corrosion cells under the above conditions by means of cathodic protection is also discussed.

Construction Features of Installing Conduit

Because of economic and public relations reasons cables to central telephone offices are placed under ground in a multi-duct vitrified clay or cement asbestos conduit system. The conduit also provides a ready means for placing or removing the cables. Manholes are placed generally at intervals of 500 to 600 feet to facilitate wire splicing in adjacent cable sections. These cables may have as many as 4242 wires under the sheath of an outside diameter not to exceed $2\frac{11}{16}$ inches.

When the conduit substructure is placed the mid-section of the conduit system is sloped to the manholes with a 3-inch fall per 100 feet as shown in Figure 1. However, due to other foreign substructures such as storm drains, sewer mains, large gas or water pipes or pedestrian tunnels, telephone cables some times must be placed under these foreign substructures. This change in normal grade may create dips or pockets in the conduit system which water can become entrapped. See Figure 2.

Methods and practices used in installing telephone conduit do not necessarily make the structure silt free or waterproof. Due to economics and, in most cases, the lack of necessity, the conduit is not encased in concrete. There are no internal stresses in the telephone cable as found in the case of power cables during fault conditions.

If the telephone conduit substructure, because of other foreign substructures, is placed with a dip at a depth where the natural water table will be above the conduit, water will be entrapped in the dip as shown in Figure 3. Placing of a bare-lead sheathed cable in the conduit and through the dip having water may create a corrosion problem due to differential aeration. Lead-sheathed telephone cable was the only type available up to 1946 when the polyethylene-jacketed cables were introduced. Supply conditions in Southern California today are such that a large percentage of the underground cables placed are still bare-lead sheathed.

Differential Aeration Corrosion

Differential aeration corrosion is caused by a difference or variation in the concentration of dissolved oxygen in the electrolyte at two places in contact with the metal. This is a type of local corrosion cell. Distances between anodes and cathodes may be small, sometimes approaching microscopic size.

Neither the currents nor the potential are measurable by any practical means.[1] These corrosion cells are formed whenever the metal is in contact with aerated solution at one place and with oxygen deficient solution elsewhere.[2] Differential aeration also accounts for corrosion at the water line.[3] If the gas above the liquid surface is air, the area below the water surface is laden with oxygen and is cathodic; whereas, lower down, attack proceeds quite freely due to the difference (decrease) in oxygen content.

In the investigation of a failure of a floating gas holder, corrosion was caused by differences in concentration of oxygen at the surface and lower depths of the sealing water.[4] Analysis showed that the sealing water surface contained dissolved oxygen, while lower down, hydrogen sulfide and other reducing agents predominated so that the metal in contact with the lower levels of water was anodic and corroded rapidly. The metal in contact with the surface layers was cathodic because of the higher oxygen concentration. Corrosion occured to a depth of 3 feet but most severely about 4 inches below the surface.

★ Revision of a paper titled "A Discussion of Measures Used to Correct Differential Aeration Corrosion of Partially Submerged Lead-Sheathed Telephone Cables" by David T. Jones, Pacific Telephone and Telegraph Co., Los Angeles, Cal., presented at a meeting of the 14th Annual Conference, National Association of Corrosion Engineers, San Francisco, Cal., March 17-21, 1958.

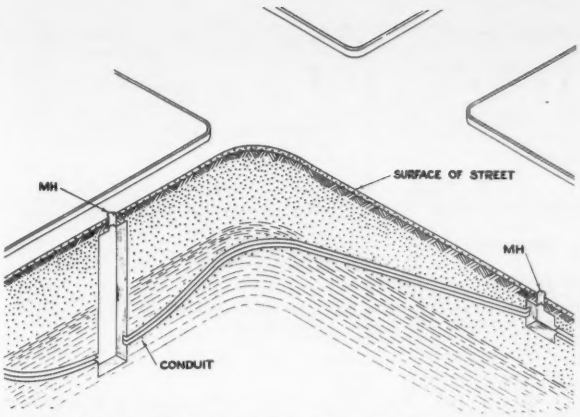

Figure 6—Telephone manhole and conduit system partially submerged in water as discussed in Case B.

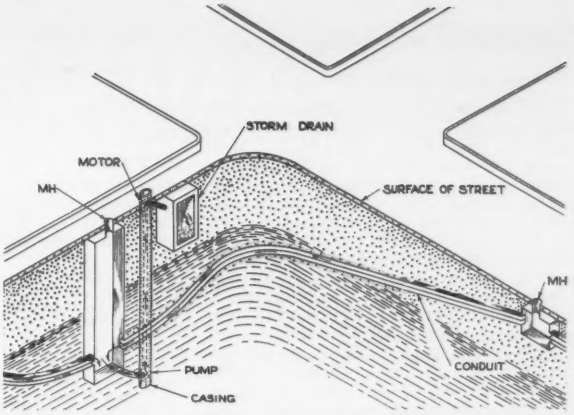

Figure 7—Telephone manhole and conduit system partially submerged in water and drained to a storm drain by an automatic sump pump as discussed in Case B.

Non-ferrous metals that are usually highly resistant to attack in water may develop severe pitting because of differences of oxygen concentrations.[4]

This difference of oxygen concentration in the electrolyte causing corrosion of lead-sheathed telephone cables is discussed in the Third Interim Report of Technical Unit Committee T-4B of the National Association of Corrosion Engineers.[5]

Some Case Histories

Case A: A number of telephone lead-sheath failures occurred on either side of a manhole located at the low point of the dip (Figure 4). The conduit substructure followed closely the street surface contour. The manhole was located in a natural underground water stream fed by artesian wells a few thousand feet away.

When the cables which failed were removed from the conduit, the point of failure was measured from either end of the section. The cable sheath at point of failure was pitted and the corrosion products, white lead carbonate, were similar to those occurring under stray current anodic corrosion conditions. The water in the manhole had a pH of 7.2. A profile curve of the conduit substructure was drawn and location of the cables and failures also was plotted on the profile curve. The failure location coincided with the measured water table level within plus or minus 6 inches. The water table level remained relatively constant throughout the year.

The potentials of the cables were —.08 volt to a lead reference electrode (placed in the dirt parkway adjacent to the manholes) at the adjacent manholes as well as the low manhole. Duct surveys made in each direction from the low manhole indicated that the cable-to-earth potentials varied from —0.08 volt at the entrance to the manhole to —0.02 volt at the points of failure. The cables were drained to a negative bus of a railway sub-station some 8000 feet away.

As there was a large storm drain a few feet away and some 6 feet lower than the manhole floor, gravity water drainage system was installed to this storm drain as shown in Figure 5.

These failures occurred some 10 years ago. The water drainage system was installed during the next year. During the past nine years, additional cables have been placed in the conduit run, but no additional failures have occurred. This gravity water drainage installation permits only fresh running water to flow over the cables. Previously, standing water with differences in oxygen content surrounded the cable, causing differential corrosion.[2, 4, 5]

Case B: This case is similar to Case A as the manhole also was located at the low point in the dip; however, a portion of the conduit in one direction was encased in concrete. The conduit section which was encased in concrete was in a curve. One end of the encasement was below the water level; the other end was some four feet above the water level. (See Figure 6.) This conduit substructure also passed through an underground stream fed by springs in the nearby hills. Because of the dip, water is entrapped in the conduit. Since this conduit was installed in 1926, all free alkali has been dissipated.

The failure locations checked relative to the water table level showed that the failure location checked within 6 inches of the average water level. The corrosion product was lead carbonate, and the water pH was 7.6. In the unencased section on the opposite side of the manhole from the encased portion where running water flowed over the cables, no cable sheath failures have been experienced. Gravity drainage cannot be used as the manhole floor is much lower than available storm drains.

To drain the manhole, a sump pump is being installed to lift water into a storm drain as shown in Figure 7.

This case again illustrates the fact that standing water creates a differential aeration local cell corrosion problem while running water causes no adverse corrosion effects.

Case C: When the conduit structure was originally placed, the grade was four feet below the street surface, but at a later date, two 7 by 9-foot storm drains were installed. A dip was created in the conduit when the telephone conduit substructure was lowered 15 feet to clear the storm drains. A manhole

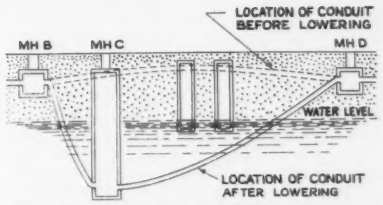

Figure 8—Telephone manhole and conduit system partially submerged in water, showing the conduit location before and after lowering because of the storm drain construction as discussed in Case C.

also was placed near the low point of the dip. (See Figure 8.) Another factor which aggravated the problem was that the storm drains followed the route of a pre-historic river. The area is now well known because of the bones of prehistoric animals and birds found entrapped in the famous LaBrea Tar Pits.

In this case, as in the other two, a check was made of the sheath failure locations against the water level. Again close coincidence was found between the water level and point of sheath failure. A duct survey was not made because all nine ducts are occupied with cables. Tests showed that from 400 to 500 gallons of water an hour which entered the manhole from the conduit structure would have to be removed. To provide a reservoir for the water to be cleared from the manhole and conduit, a pump with a static lift of some 25 feet would be required. Size of the reservoir was designed to provide a short working cycle for the pump. This sump or reservoir was to be a 30-inch steel or concrete pipe placed vertically beside the existing manhole.

The estimated cost for this project was $6000. This seemed too expensive but the cost was justified by the importance and amount of telephone service in this cable. Telephone cables in this trunk route which extends for some 8 miles westward from the downtown area of Los Angeles are under cathodic protection. At the location in this route in which the cables are below the storm drain, the cable potential to a copper copper-sulphate half cell reference electrode, located over the cable run and 10 feet from the manhole, is less than —0.60 volt which offers no cathodic protection to the lead cable sheaths.

(Continued on Page 118)

Differential Aeration—

(Continued From Page 117)

In view of the cost of installing the sump pump, it was thought that two questions had to be answered before making a final decision to install the pump: First, what effect did the water in the manhole and conduit, which partially, submerged the cables, have on the cable potential to a copper copper-sulphate half cell reference electrodes? Second, could the application of cathodic protection at the affected manhole and adjacent conduit substructure provide cathodic protection to the cables in this area and also provide protection against voltages created by local corrosion cells?

Figure 9 shows schematically the general layout of the area and the relative location of the existing cathodic protection stations adjacent to the area in question. To answer the first question, a series of tests were made with Manhole C and adjacent conduit drained and not drained of water and with Rectifier I and II operating and not operating.

Figure 10 indicates the test results and conditions under which the tests were conducted. When the cables are unprotected and rectifiers non-operative, there is a considerable improvement in the potential of the cables to the copper copper-sulphate half cell reference electrode, located over the cables and 10 feet from the manhole, when the water is removed as shown by Curves 1 and 2. Curve 3 shows the results of the tests while cathodic protection is being applied by rectifiers I and II and with water in the Manhole C. Curve 4 shows that a large change in cable potential to the copper copper-sulphate reference electrode is obtained when the water is not allowed to stand over the cables and in Manhole C.

From these tests, it was determined that the cable potential to the reference electrode could be improved by eliminating the water.

The second question of whether the application of a cathodic protection station at Manhole C could provide the necessary protection to the cable sheaths when under water was determined by making a series of trial cathodic protection tests. Results of these tests are shown in Figure 11. With an output of 15 amperes (Curve 3), no great change was made in the cable potential to the copper copper-sulphate reference electrode at Manhole C. An increase of the current output would increase the effects of interference current upon other foreign metallic substructures in the immediate area. These test results indicated that the idea be abandoned of placing an auxiliary cathodic station at Manhole C and that an automatic sump pump be installed to allow the water to flow over the cables but not to stand in the manhole or adjacent conduit structure as shown in Figure 12.

Results of the test indicate that the trial cathodic protection station did not make a sufficient change in the cable potential to the copper copper-sulphate reference electrode to provide the minimum protective voltage of —0.70 volts. If sheath protection cannot be obtained, the small voltage created by the local corrosion cells caused by differential aeration could not be nullified by the current from the cathodic station.

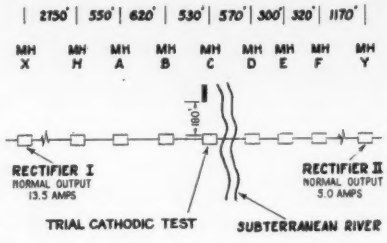

Figure 9—General plan of area discussed in Case C, showing relative locations of manholes and adjacent rectifiers, normal output of the rectifiers, and location of auxiliary trial cathodic protection anode bed.

MH H 550' A 620' B 530' C 570' D 300' E 320' F
CABLE POTENTIAL TO COPPER HALF CELL
·30
·40
·50
·60
·70
·80
TO RECTIFIER I
RECTIFIERS I & II OFF NO WATER IN MH C
RECTIFIERS I & II OFF WATER IN MH C
RECTIFIERS I & II ON WATER IN MH C
RECTIFIERS I & II ON NO WATER IN MH C
TO RECTIFIER II

Figure 10—Chart showing changes in cable potential to copper copper-sulphate half cell reference electrode when water is drained and not drained from Manhole C while Rectifier I and II are operating and not operating—as discussed in Case C.

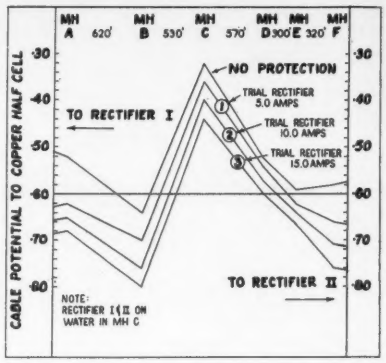

Figure 11—Chart showing changes in cable potential to copper copper-sulphate half cell reference electrode while water remains in Manhole C and with various current outputs of an auxiliary trial cathodic station connected to cables in Manhole C—as discussed in Case C.

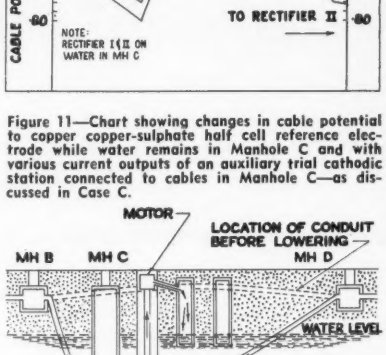

Figure 12—Telephone manhole and conduit system partially submerged in water and drained to a storm drain by an automatic sump pump as discussed in Case C.

Conclusions

The number of sheath failures caused by differential aeration in clean water (no mud or silt deposits) have been less than 25, but the cost to replace the cables has been higher than average costs for normal replacements because of the need for additional manpower to handle and maintain pumps. If the cable is under gas pressure, the severity of service interruption is minimized.

Now that corrosion possibilities are being evaluated by the design and construction engineers, a better approach is being made toward elimination of severe dips or pockets in the conduit substructure. When dips are necessary, only the use of non-metallic sheathed cables such as polyethylene jackets are specified by the corrosion engineer.

In severe cases, difficulties will be encountered with installing cathodic protection that will provide sufficient protection to care for the cables partially submerged and to provide sufficient voltage to nullify the voltages set up by the local corrosion cells of differential aeration.

A corrosion problem is introduced when bare-lead sheathed telephone cables are partially submerged in standing water or in entrapped water where the concentration of oxygen dissolved in the water may vary from surface to areas below the surface thus setting up minute difference in potential. Voltages and currents developed by these cells are considered small; experience has shown that it takes years to create a corrosion area sufficient for the sheath to fail and allow moisture to enter the cable.

Experience has also shown that in those cases where the cables are submerged totally or partially in running water, no sheath failures have occurred due to differential aeration corrosion.

The decision to drain the manholes was made after considerable investigation of cost studies and engineering considerations. From these data, it was considered the most economic and expeditious method of resolving the corrosion problem involving differential aeration in these special or specific cases.

Acknowledgments

The author wishes to express his appreciation to Messrs. K. G. Compton, and V. B. Pike of the Bell Telephone Laboratories and S. A. Haviland and A. F. Minor of the American Telephone and Telegraph Company for their helpful suggestions; to E. L. Addington and D. W. Seely for their help in preparing the sketches and to his wife, Kay, for her helpful suggestions and discussions during the course of preparing this paper.

References

1. K. G. Compton. Electrical Measurements and Their Interpretation in Underground Cable Corrosion Problems. *Corrosion*, **14**, 237t (1958) May.
2. H. H. Uhlig, Corrosion Handbook. John Wiley and Sons, Inc., New York, N. Y. Fifth printing, August, 1955.
3. U. R. Evans. Corrosion Passivity and Protection. Longmans, Green and Co., New York, N. Y., 1946, page 276.
4. F. N. Speller. Corrosion Causes and Prevention. McGraw-Hill Book Co., Inc., New York, N. Y., 1951, pp 363-364.
5. Cell Corrosion on Lead Cable Sheaths—Third Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. *Corrosion*, **12**, 257t (1956) May.

CORROSION ABSTRACTS

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CORROSION ABSTRACTS

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1. GENERAL

1.2 Importance

1.2.5

Safety Considerations for Handling Plutonium, Uranium, Thorium, the Alkali Metals, Zirconium, Titanium, Magnesium and Calcium. ELLIS L. STOUT, Compiler. Los Alamos Scientific Lab. U. S. Atomic Energy Commission Pubn., LA-2147, Sept. 4, 1957, 24 pp. Available from Office of Technical Services, Washington D. C.

This report compiles from various sources safety considerations for work with the special metals plutonium, uranium, thorium, the alkali group, magnesium, titanium, calcium and zirconium. General criteria to be observed in handling all of these metals and their alloys are listed, as well as characteristics of individual metals with regard to health hazards, pyrophoricity, explosiveness and other chemical reactions, in both handling and storage. (auth)—NSA. 15411

1.2.5, 3.4.6, 3.5.9

Combustion of Metals in Oxygen. A. V. Grosse and J. B. Conway. Temple Univ., Philadelphia. Ind. Eng. Chem., **50**, 663-672 (1858) April.

As part of a study of methods of producing high temperatures, the combustion of metals in oxygen was investigated. The basic objective was developing techniques to produce and utilize high temperature sources. Metals which burn to produce high temperatures are discussed in terms of their location in the periodic table. The skating sun phenomenon suggests a high temperature radiation source. Metals are classified depending on whether they ignite above or below their melting point. The operating characteristics of powdered metal-oxygen flames are described in detail. The work reported is primarily fundamental research, although combustion of aluminum can yield a source of high intensity thermal radiation. Powdered metal-oxygen flames are highly effective in cutting through thick sections of concrete and various ceramic materials. (auth)—NSA. 16149

1.2.5, 6.3.15

Hazards and Safety Precautions in the Fabrication and Use of Titanium. F. D. PETERSEIM. Titanium Metallurgical Lab., Battelle Memorial Inst., Jan. 25, 1957, 22 pp. Available from Office of Technical Services, Washington, D. C. (Order PB 121628).

Pertinent information on the health and safety hazards encountered in production, fabrication and use of titanium has been reported. The survey indicated that under certain conditions titanium is combustible and explosive; thin chips and fires can ignite and burn with intense combustion and even explode when dispersed in the air. Under some conditions titanium sponge would ignite too. However, massive ingots or sheets do not ignite easily. Explosive reactions were observed during stress-corrosion studies of titanium in red fuming nitric acid. Though titanium itself has not been found to be toxic, some titanium compounds, alloying ingredients and chemicals used in titanium processing are. To date no effective means for extinguishing titanium fires has been found. However, the experience showed that titanium fires can be controlled by the use of conventional powders.—NSA. 13851

1.6 Books

1.6, 6.3.9

The Metal Molybdenum. Julius J. Harwood, Editor. Proceedings of a Symposium Sponsored by the Office of Naval Res., Held in Detroit on 18-19 September, 1956. Book, 1958, 696 pp. Available from: The American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio.

Contents: A. J. Herzig, The Potential and Future of Molybdenum and Its Alloys; R. R. Freeman, Properties and Applications of Commercial Molybdenum and Molybdenum Alloys; C. H. Toensing, Molybdenum Metal Powder; H. Scott, W. A. Taebel and D. D. Lawthers, Consolidation of Molybdenum by Powder-Metallurgy Practice; G. A. Timmons and R. G. Yingling, Arc-Melting Molybdenum; W. L. Bruckart, The Working of Molybdenum and Its Alloys; J. D. Nisbet, Fabrication at Very High Temperature under a Controlled Atmosphere; W. N. Platte, Welding of Molybdenum; R. E. Monroe, Brazing of Molybdenum; S. Senderoff, Techniques for Coating Metals with Molybdenum; R. Maddin, The Behavior of Molybdenum Single Crystals under Various Stress Conditions; J. H. Bechtold and E. T. Wessel, Ductile-to-Brittle Translation in Bolybdenum; H. S. Spacil and J. Wulff, Effects of Oxygen, Nitrogen, and Carbon on the Ductility of Wrought Molybdenum; M. Semchyshen, Development and Properties of Arc-Cast Molybdenum-Base Alloys; R. I. Jaffee, Powder-Metallurgy Molybdenum-Base Alloys; M. W. Mallett and W. R. Hansen, Determination of Gases in Molybdenum; W. C. Coons, Fractographic and Metallographic Techniques for Molybdenum and Molybdenum-Base Alloys; R. T. Begley, Molybdenum for Aircraft Gas-Turbine Applications; J. J. Harwood, The Protection of Molybdenum Against High-Temperature Oxidation; R. Q. Barr, M. Semchyshen and I. Perlmutter, Effects of Hot-Cold Work on the Properties of Molybdenum Alloys; J. J. Russ and G. E. Schrader, Forging of Molybdenum Alloy Turbine Blades; L. North-

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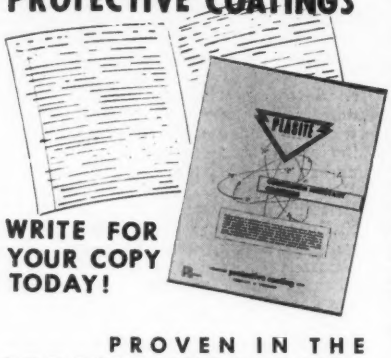

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cott, Molybdenum Research and Development in Great Britain; R. Kieffer and E. Pipitz, Sintered and Arc-Melted Molybdenum Alloys; Appendix I: Molybdenum Binary Constitutional Diagrams; Appendix II: Molybdenum Metallurgy: A Bibliography.—MA. 17391

1.6, 6.3.20, 8.8.5

Zirconium. Metallurgy of the Rarer Metals. G. L. Miller. Book, Second Edition, 1957, 569 pp. Published by the Academic Press, Inc., New York.

The methods for the production of zirconium metal are divided into three sections, each occupied by one chapter. The various melting techniques employed in the metallurgy of zirconium are described in detail. The properties of the metal are detailed, and a chapter is devoted to the reactions of zirconium with the common gases. The outstanding property of zirconium—its resistance to chemical corrosion—is discussed at length. The fabrication and mechanical properties of various zirconium alloys are discussed in detail.—NSA. 16985

1.6, 6.3.5

Technology of Columbium (Niobium). Edited by B. W. Gonser and E. M. Sherwood, Book, 1958, 120 pp. Papers Presented at the Symposium on Niobium of the Electrothermics and Metallurgy Division of the Electrochemical Society, Held on 15-16 May 1958 in Washington, D. C. New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd.

Contents: J. R. Darnell and L. F. Yntema, The Element Niobium and Its Compounds; K. B. Higbie, Source of Niobium; R. L. Carmichael, Economic Aspects and the Supply Situation for Niobium; M. E. Sibert, A. J. Kolk, Jr. and M. A. Steinberg, A Review of the Extractive Metallurgy of Niobium; E. Epremian, Niobium in Nuclear Reactors; Joan L. Tews and S. L. May, Recent Developments in Separating Tantalum and Niobium by Solvent Extraction; A. J. Kolk, Jr., M. E. Sibert and M. A. Steinberg, Investigation of Electrolytic Processes for Preparation of High-Purity Niobium Metal; J. F. Reed, Analysis for Certain Metallic Impurities in Niobium; W. F. Harris, The Determination of Nitrogen and Oxygen in Niobium; F. J. Anders, Jr., and W. I. Pollock, Tensile Properties and Rolling Textures of Niobium Sheet; E. T. Wessel and D. D. Lawthers, The Ductile-to-Brittle Transition in Niobium; J. W. Semmel, Jr., The Effect of Rare-Earth-Metal Additions on the Ductility of Arc-Melted Group-Va Metals; J. G. Beach, Electroplated Metals on Niobium; H. P. Kling, The Development of Oxidation-Resistant Niobium Alloys; F. J. Clauss and C. A. Barrett, Preliminary Study of the Effect of Binary-Alloy Additions on the Oxidation-Resistance of Niobium; C. A. Barrett and F. J. Clauss, Oxidation of Niobium-Chromium Alloys at Elevated Temperatures; W. D. Klopp, C. T. Sims and R. I. Jaffee, Vacuum Reactions of Niobium During Sintering.—MA. 17375

2. TESTING

2.2 On Location Tests

2.2.2, 2.3.2, 4.3.3, 4.2.4

Comparison of Results of Corrosion-Tests in Industrial Atmospheres and Short-Time Laboratory Tests in Sulphur Dioxide-Containing Atmospheres. (In German.) A. Kutzelnigg. Werkstoffe u. Korrosion, **9,** 429-434 (1958) July.

Characteristics of industrial atmospheres and notes on role of sulfur dioxide in atmospheric corrosion. Description of the Testor corrosion-testing equipment for sulfur dioxide-containing atmospheres developed by Kesternich is given. Discussion of possible reduction in sulfur dioxide concentration and elimination of carbon dioxide content of test atmosphere is included. Other test methods based on sulfur dioxide-containing atmospheres, and comparison of long-term and accelerated corrosion data, showing that sulfur dioxide test technique gives results in good agreement with industrial exposures, particularly for nickel electrodeposits, zinc coatings and other paint systems are discussed.—INCO. 16939

2.2.5, 5.4.5

Results of a Field Corrosion Test on Several Steels Protected by Different Paint Coats. Gerhard Becker. Stahl und Eisen, **78,** No. 17, 1186-1191 (1958) August 21.

Corrosion tests in the openair of a duration of 22 years on rolled steel products protected by paint coats. Relations between the life of the paint coats and the chemical composition of the steels, particularly the copper and silicon contents. Influences of the preparation of the steel base, of the structure of the covering paint layers and of the method of applying the paint.—SE. 16444

2.3.5, 5.4.5

Pinhole Test of Resin Coating by Electrolysis of Zinc Sulfate Solution. M. Kanazawa. J. Metal Finish. Soc., Japan, **9,** No. 4, 137-143 (1958) April.

Due to probable pinholes of the rust-proof coating, the rust of the base metal appears sometimes on the surface. This report describes a method of detecting pinholes using electrolysis of zinc sulfate solution.—JSPS. 16776

2.2.2, 5.4.5, 4.2.1

Influence of Climate on Paint Systems in the Netherlands. G. Lewin and A. Zaalberg. Verfkroniek, **31,** No. 6, 240-242 (1958).

During the years 1956-1957, a number of test panels painted with several types of coating systems were exposed in different places in the Netherlands. As the behavior of these systems was well known from years of practice, the influence of the local climate could be observed by comparing the deviations from the behavior of the systems under normal circumstances. The influence of an industrial climate was rather destructive, as could be expected, but it was remarkable that, in an area of land regained from the sea, the destruction of the paints was greater than in towns. —RPI. 17474

2.2.7, 5.4.5, 8.9.5

Ship Trials of Vinyl Underwater Compositions. H. A. Laurie and B. Parkes. Paint J. of Australia & New Zealand, **3,** No. 4, 9-17 (1958).

This report covers trials on ships of vinyl underwater paints (e.g., paints conforming to Specification MIL-P-15929-15931) over a period of approximately 3 years. The results of assessment for each ship are given and comparisons are made with mercurial underwater compositions at present used

by the Royal Australian Navy. The results indicate that vinyl systems have a fouling-free life on ships of about 12 months, which is approximately double the life of mercurial systems. Corrosion resistance for a similar period is considered to be good, provided certain conditions of surface preparation and application as detailed in the report are met.—RPI. 17446

2.3 Laboratory Methods and Tests

2.3.4

The Detection of Cobalt and Nickel in Qualitative Analysis. R. E. D. Clark. Analyst, **83,** No. 988, 431-432 (1958) July.

Presents scheme for detecting presence of both cobalt and nickel in black precipitate of sulfides, without need for prior dissolution in acid. Add minute specks of black precipitate to 0.5 ml of pyridine containing trace of zinc complex of toluene-3:4-dithiol and warm solution; blue color indicates cobalt. Add speck of black precipitate to 0.5 ml of quinoxaline-2:3 dithiol and boil; red color (with eventual formation of red precipitate) indicates nickel.—INCO. 17181

2.3.6, 3.7.4

Experience with a Japanese Light Optical Method for Determination of Orientation of Single Crystals. (In German.) F. Haessner and W. in der Schmitten. Z. Metallkunde, **49,** No. 10, 507-509 (1958) October.

Reviews method of M. Yamamoto and presents results of orientation experiments with nickel, copper, aluminum and zinc crystals. Possible accuracy is ±0.1-0.2 degrees. At restriction to accuracy of ±2 degrees, determination of orientation requires less than 5 minutes. —INCO. 17396

2.3.6, 3.7.4, 6.4.2

Grain Boundary Etching on Pure Aluminum. I. Braun, F. C. Frank and G. Meyrick. Phil. Mag., **3,** No. 35, 1312-1317 (1958) Nov.

In the etching of recrystallized aluminum (both of 99.99 percent purity, and zone-refined material) in Lacombe and Beaujard's etchant, the grain boundaries are found to resist attack immediately after electropolishing, but to become susceptible to severe attack after periods of a few days at room temperature. It is suggested that this behavior is due to diffusion of impurities along the grain boundaries, into the oxide film. (auth).—ALL. 17188

2.3.7, 2.4.2, 5.3.4

Microchardness Testing—Equipment, Techniques, Applications. V. E. Lysaght. Am. Chain and Cable Co., Inc. Tool Engr., **41,** No. 4, 87-90 (1958) October.

Description of microhardness testing techniques and procedures and suggestions for areas of possible application. Table gives results of hardness tests of plated surfaces made on electro-deposits of cadmium, silver, zinc, copper, nickel and chromium. Such factors as current density, temperature and composition of plating solution, variation in hardness from outside to inside of plate and structure of electrodeposited metal, all influence hardness determination. A microhardness testing instrument is used by a large control manufacturer for controlling the hardness of bimetal strip. This bimetal unit is made up of 2 layers which deflect when subjected to changes in temperatures. Largest percentage of material used in the bimetal strips is nickel steel and chromium plated steel. Alloys such as brass, stainless steel, chromium iron and silicon bronze are also combined into thermostat metals. Photos, diagrams.—INCO. 17463

2.3.7, 3.4.9

Corrosion by Condensed Humidity. A Simple Testing Procedure. (In French.) S. C. Britton. Corrosion et Anticorrosion, **6,** 346-351 (1958) Oct.

Method devised to reproduce as closely as possible conditions of exposure to which equipment, boxed or under shelter, is subjected during storage and transport. Small specimens of metal are fastened to underside of glass plate placed horizontal in open air. Method is faster than exposure tests under shelter and gives more accurate results on behavior of materials than damp chamber tests. Results on corrosion resistance of tin plate, metallic coatings and other methods of protection. 5 references.—MR. 17288

2.3.7, 3.5.9

Temperature Measurement in Solids. W. H. Giedt. Detroit Controls Corp. Product Eng., **29,** No. 29, 65-67 (1958) July 21.

Increased operating temperatures in highly stressed materials call for knowing exact temperature at exact point. Use of thermistors, resistance elements and thermocouples for such measurements is discussed. One recent application is resistance coil of 0.001-in. diame-

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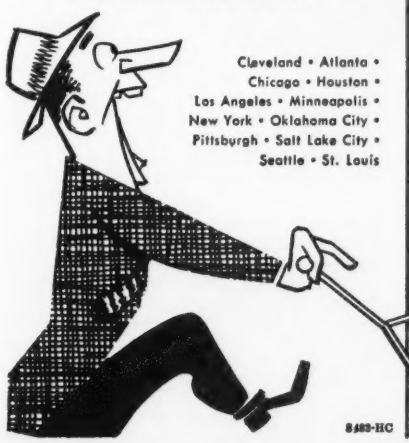

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2.3.7, 7.1, 3.5.8

The Axial Test Bore in Turbo-Generator Rotors. K. Kreitz. Paper before Am. Soc. Testing Materials World Metals Congress, Philadelphia, Nov. 11, 1957. Am. Soc. Testing Materials Special Technical Pubn. No. 231, 37-43, 1958.

Description of break tests of rotating disks performed to explore more accurately the causes for the disintegration of turbo-generator shafts. Results show that the mean break stress rather than the maximal local stress equals the tensional strength of faultless disks. Cracks in the metal reduce the break stress by 40-80 percent depending on size and location. Their presence reduced the break stress more in brittle than in tough, tempered steel. Steels used in tests included a 1.9 nickel steel. Graphs, tables.—INCO. 17452

2.3.6, 3.5.8, 6.3.6

Surface Structure of Slip Bands of Copper Fatigued at 293, 90, 20 and 4.2 K. D. Hull. J. Inst. Metals, **86**, Pt. 9, 425-430 (1958) May.

Slip bands produced during fatigue deformation of high-purity copper at temperatures between 293 and 4.2 K were studied with the optical and electron microscopes. Replicas of surface reveal changes in contour within individual slip bands, above and below the surface. Extrusions and intrusions are formed in slip bands at all the temperatures of testing, and their formation is not suppressed at 4.2 K. Intrusions were detected in specimens fatigued for less than 1% of the estimated lifetime, and it is believed that they constitute the first fatigue cracks. The observations are discussed in terms of recent theories of extrusion and intrusion. Photomicrographs, 17 references.—INCO. 16499

2.3.6, 3.4.9, 6.4.2

The Electron Metallography of Some Aluminum Alloys. F. D. Leipziger. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-1880, Oct., 1957, 9 pp. Available from Office of Technical Services, Washington, D. C.

The methods for polishing and replicating aluminum alloy specimens for study with an electron microscope are reported. The three alloys chosen because of their resistance to corrosion in high temperature water were: a 6% copper alloy, a 1% nickel, 1% iron alloy, and a 1% nickel, 0.5% iron alloy. This work involved the examination with an electron microscope of these three alloys, both before and after varying periods of exposure to water at 680 F. The preparation of specimens for microscopic examination is also described. (auth)—NSA. 16225

3. CHARACTERISTIC CORROSION PHENOMENA

3.5 Physical and Mechanical Effects

3.5.8, 2.3.7, 2.4.2, 1.6

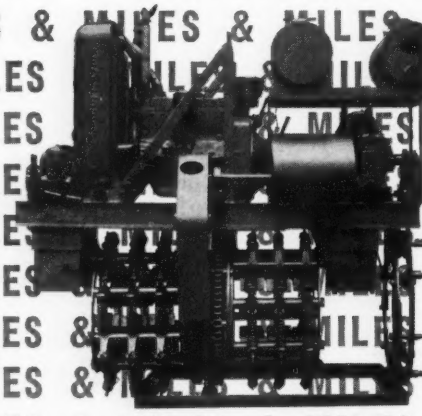
Symposium on Large Fatigue-Testing Machines and Their Results. Am. Soc. Testing Materials. Presented at the Sixtieth Annual Meeting of the A.S.T.M., Held on 18 June 1957 in Atlantic City. ASTM Special Technical Pubn., No. 216, 151 pp., 1958. Available from The Society, 1916 Race Street, Philadelphia 3, Pennsylvania.

Contents: J. M. Lessells: Symposium on Large Fatigue-Testing Machines and Their Results; H. V. Cordiano: A Unique Machine for Large-Scale Fatigue Testing; E. J. Eckert: Torsional-Fatigue Testing of Axle Shafts; H. W. Foster: Fatigue Testing of Airframe Structural Components; T. W. Bunyan: Fatigue Performance of Marine Shafting: Laboratory and Service Tests; O. J. Horger and H. R. Neifert: Fretting Corrosion of Large Shafts as Influenced by Surface Treatments; F. C. Eaton: Fatigue Tests of Large Alloy-Steel Shafts; R. Michel: Influence of Operating Experience and Full-Scale Tests on Propulsion-Shafting Design of U. S. Navy Ships; G. V. Uzhik, M. J. Galperin and A. A. Zooykova: Sudden Fracture of Machine Parts and Structure Elements; S. V. Serensen and M. E. Garf: Determination of Dynamic Loading in Full-Size Fatigue Tests and Some Results. —MA. 17309

3.5.8, 6.4.2, 6.2.5

On Stress Interaction in Fatigue and a Cumulative Damage Rule. Part I. 2024 Aluminum and SAE 4340 Steel Alloys. A. M. Freudenthal and R. A. Heller. Columbia Univ. U. S. Wright Air Development Center, Technical Report No. 58-69, Part I, June 1958, 48 pp.

Object of investigation was to determine effects of stress-interaction, under randomly varied exponentially distributed stress amplitudes representing gust



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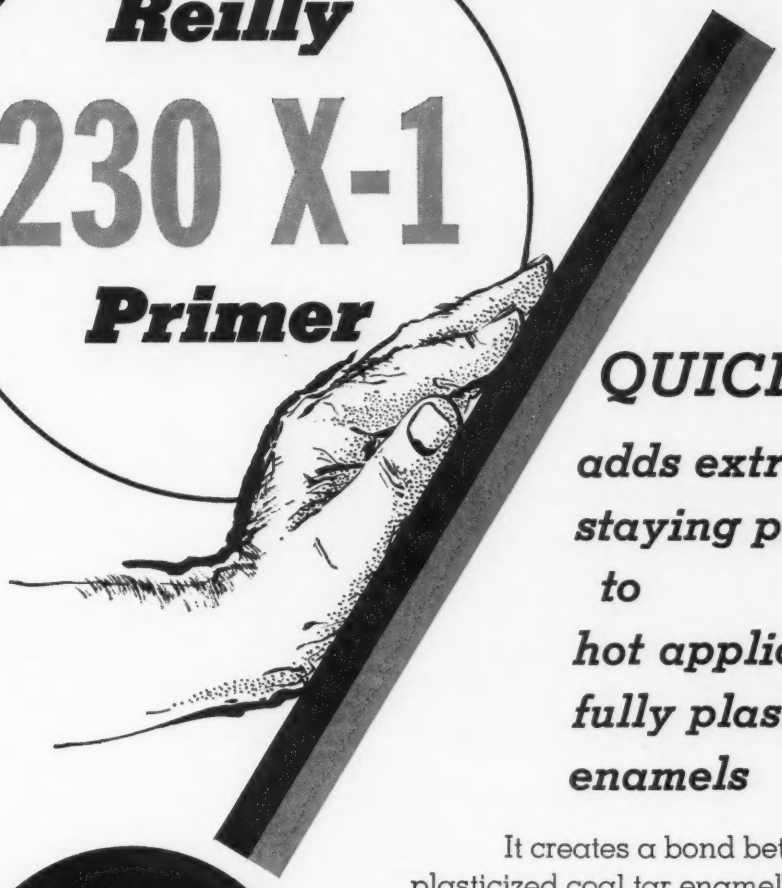

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and maneuver loads on aircraft wings, on fatigue life of smooth SAE 4340 steel and 2024 aluminum specimens. A quasi-linear rule of cumulative damage based on stress-interaction and fictitious S-N diagram produced by such interaction is proposed and confirmed by random fatigue tests. Developed relations permit fairly reliable prediction of fatigue lives of such specimens under exponential stress-amplitude spectra of arbitrary slope and stress-range. Damage effect of low stress-amplitudes when mixed with infrequent high amplitudes is demonstrated. In steel this effect eliminates conventional endurance limit as a significant design value under varying stress amplitudes. Tables, graphs.—INCO. 17261

3.5.8, 6.3.6

Cracking of Mercury-Coated Alpha-Brass under Alternating Strain. W. A. Wood. J. Inst. Metals, **86,** No. 5, 228-231 (1957-58).

Specimens of annealed α-brass coated with mercury were subjected to alternating plastic strains of known amplitude. In this way the phenomenon of mercury-cracking was utilized to determine how effective different amplitudes may be in building up local internal stresses, and so to test theories which attribute fatigue failure to local internal stresses, and so to test theories which attribute fatigue failure to local development of high stresses. The effectiveness of the alternating strain decreases sharply below a particular range of amplitudes, and as a result of this and related effects it is suggested that two mechanisms of fracture exist, one for large amplitudes and one for small. Reasons for this difference are put forward. (auth)—NSA. 17077

3.5.9, 3.8.4

Behavior of Materials at Very High Temperatures. Irving J. Gruntfest and Lawrence H. Shenker. General Electric Co. Ind. Eng. Chem., **50,** No. 10, 75A-76A (1958) October.

The over-all complex process of thermal deterioration of materials at high temperatures is resolved into simpler and more independent phenomena, including heat absorbing capacity, gas rate generation, liquefaction and vaporization, spalling and oxidation. Materials are considered from these standpoints in choosing the best material for a specific application.—NSA. 17400

3.5.9, 3.8.4, 6.3.10

The Effect of Temperature on the Magnetic Properties of Nickel-Iron Alloys. J. J. Clark and J. F. Fritz. Westinghouse Elec. Corp. U. S. Wright Air Development Center, Technical Note No. 57-434, December, 1957, 33 pp. Available from Office of Technical Services, Washington D. C. (Order PB 131799).

Reports of effects of temperature variation on the d-c magnetic properties of 6 nickel-iron alloys—Hipernik, Deltamax, Supermalloy, Hipernik V, Mo Permalloy and Hymu 80. Normal magnetization curves for various temperatures between —60 C and +250 C are presented, together with curves illustrating the behavior of saturation induction, remanence, and coercivity over this temperature range. It is found that the normal permeability of Hipernik, Mo-Permalloy, Supermalloy and Hymu 80 alloys is relatively independent of temperature at one induction: 6 kilogausses for the Hipernik alloy and between 4.5 and 5.5 kilogausses for Mo-Permalloy, Supermalloy and Hymu 80 alloys. A dependence of the d-c magnetic properties of Hipernik V and Deltamax alloys on temperature cycling is also reported. Graphs, tables.—INCO. 17029

3.5.9, 6.3.10

Effects of Temperature on Magnetic Properties of Nickel-Iron Alloys over Temperature Range —60 to +250C. J. F. Fritz and J. J. Clark. Westinghouse Electric Corp. Elec. Mfg., 62, No. 5, 135-139 (1958) Nov.

Tabular and graphic data on effects of temperature on permeability, saturation induction, remanence, and coercive force of 6 commercial nickel-iron alloys: Hipernik V, Hipernik, Deltamax, 4-79 Mo-Permalloy, Supermalloy and Hymu 80. Tests were first performed at intervals of increasing temperature, then repeated at decreasing temperatures to determine temperature hysteresis or aging of materials.—INCO. 17278

3.5.9, 6.3.20

The High Temperature Oxidation of Zircaloy in Water. W. A. Bostrom. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-104, March 19, 1954 (Declassified March 21, 1957), 19 pp. Available from Office of Technical Services, Washington, D. C.

The oxidation rates of Zircaloy-2 and Zircaloy-B maintained at temperatures between 1300 C and 1860 C while submerged in water have been measured. The observed rates are approximately those which would be expected from the extrapolation of existing data for zirconium in air and the reaction does not become violent or autocatalytic in nature even at temperatures above the melting point. (auth).—NSA. 16133

3.6 Electrochemical Effects

3.6.8

Impedance at Polarized Platinum Electrodes in Various Electrolytes. James N. Sarmousakis and Manfred J. Prager. J. Electrochem. Soc., **104,** No. 7, 454-459 (1957).

The measurement by an a-c-bridge method and the interpretation of the impedance of bright platinum in Normal potassium chloride, Normal potassium bromide and Normal potassium iodide as a function of polarizing voltage and a-c frequency are described. Factors are briefly discussed which may affect the dependence of impedance on frequency for the electrical double laver at a rough surface. 20 references.—MA. 17054

3.6.5, 3.6.6, 3.6.8, 3.8.2

Fundamentals of the Theory of Electrodes and Galvanic Cells. Erich Lange and Pierre Van Rysselberghe. J. Electrochem. Soc., **105,** No. 7, 420-428 (1958) July.

An outline of ideas which have been used as guides for the work of the Commission of Electrochemical Nomenclature and Definitions is presented. The work is divided into five sections: 1) electrochemical two-phase systems—single electrodes; 2) overpotentials at electrodes with diffusion layers; 3) ideal galvanic cells; 4) real galvanic cells—reference cells; 5) some remarks concerning multiple electrodes. 13 references.—MA. 17445

3.6.8, 3.8.4

Relation Between Hydrogen Overvoltage on Alloys and Their Interatomic Distances. (In Russian.) N. S. Fedorova. J. Phys. Chem. (Zhur. Fiz. Khim.), **32,** No. 3, 506-511 (1958).

The hydrogen evolution potential on electrodeposited iron-nickel alloys differs considerably from the potential of pure metals. At current density > 1600 amp/cm² there is a definite relationship between the alloy composition and hydrogen overvoltage. For the majority of the alloys the relationship between hydrogen overvoltage and log. Current density may be represented by two intersecting straight lines with different b coefficients of Tafel's equation of magnitudes varying with current density and with the composition of the alloy and the solution. The comparison of the hydrogen evolution potentials at high current density, and the interaction distances confirms Khomutov's theory. The hydrogen overvoltage reaches a minimum for interaction distances of 2.76-2.74 A. 13 references.—MA. 17277

3.6.8, 4.3.2, 3.5.9, 6.3.19

The effect of Current Density, Temperature and Sulphuric Acid Concentration on the Hydrogen Overvoltage of Zinc. (In Russian.) A. L. Rotinyan, N. P. Fedot'ev and Li Un Sok. J. Phys. Chem., USSR (Zhur. Fiz. Khim.), **31,** No. 6, 1295-1304 (1957).

Hydrogen overvoltage (η) on zinc electrode in sulfuric acid (0.01-5 Normal) was studied at 20-80 C. At higher polarizing currents η is related to log i, and is independent of sulfuric acid concentration in the range 0.01-1 Normal; at higher sulfuric acid concentration η decreases. The slopes of the lines $d\eta/d \log i = 2.3\ Rt/\alpha F$, where α was found to be constant $= 0.5$. This confirms the theory of retarded discharge assuming $i_k = i_1$. On decreasing the polarizing current η decreases initially, owing to dissolving of zinc, then remains independent of c.d. The c.d. when this decrease occurs, $\propto$ temperature and sulfuric acid concentration and is independent of the null-charge potential of zinc. Rate of dissolution of zinc is an exponential function of sulfuric acid activity. Energy of activation $= 4.6$ kcal/mole. Graphical representation of stationary potentials against log of H^+ activity has a slope of 25-30 mV against the theoretical 35-41 mV. This comparison can be regarded as satisfactory to the first approximation. ±13 references.—MA. 17071

3.3.6, 4.3.2, 5.8.2, 6.2.2, 6.3.6

Galvanic Corrosion of Cast Iron and Brass in Acids in the Absence and Presence of Inhibitors. (In German.) Willibald Machu and M. G. Gouad. Werkstoffe u. Korrosion, **9,** 699-715 (1958) Nov.

Galvanic corrosion of cast iron and brass in sulfuric acid, phosphoric acid, hydrochloric acid plus sulfuric acid, hydrochloric acid plus phosphoric acid, sulfuric acid plus phosphoric acid, with and without inhibitors. Galvanic corrosion independent of that caused by local cells, amounts usually to about 1 per cent of total. Inhibitors affect local cell corrosion much more, increasing proportional effect of galvanic corrosion. Mixtures of inhibitors give better protection. Inhibition occurs at both anode and cathode of corrosion cell. 11 references.—MR. 17481

3.6.6, 6.4.2, 5.9.4, 8.1.2

About Some Problems of Contact Corrosion of Aluminium in Buildings. (In French.) S. Acimovic, F. Prodbrez-

nik and S. Vuckovic. Alluminio, **27,** No. 12, 533-540 (1958) Dec.

Results of tests carried out on architectural aluminum material which was either not surface treated, or was anodized without being dyed, or color-anodized and the effects of concentration-cell and galvanic corrosion were observed. Data concerning weight loss and surface marks of these materials in contact with steel, tinplate, concrete, plaster, mortar, beech and pine wood, polyvinyl chloride plastics and bituminous paper are tabulated. It is shown that the otherwise outstanding protective properties of anodic coatings have little value, or none at all, when aluminum is in contact with or in the presence of zinc, plaster, wood concrete and steel.—ALL. 17155

3.6.6, 6.4.2, 4.6.11

The Behaviour of Aluminium in Contact with Other Metals in Marine Atmospheres. E. Zurbrügg. Rev. Aluminium, No. 244, 647-650 (1957).

Zurbrügg made accelerated corrosion tests in sea-water on a number of alloys used in shipbuilding (chiefly aluminum-3% magnesium and aluminum-magnesium-silicon) both untreated and anodized in contact with bolts and supporting brackets of light alloy, steel, cast iron, bronze and brass. The poorest results were shown by copper-base alloys and the best by galvanized iron. —MA. 16358

3.6.8, 3.8.2

Electrochemical Polarization. Pt. II. Ferrous-Ferric Electrode Kinetics on Stainless Steel. M. Stern. Paper before Electrochem. Soc., Washington, May 12-16, 1957. J. Electrochem, Soc., **104,** No. 9, 559-563 (1957) Sept.

Oxidation-reduction kinetics of the ferrous-ferric sulfate system were measured on Type 304 surface. Data completely support theoretical equations which describe potential-current relationships for the system. Analysis applies to reversible electrodes and to corroding electrodes where potential is determined by 2 intersecting activation over-voltage functions. Analysis permits calculation of electrochemical constants with minimum number of experimental observations. Possibility of determining anode-to-cathode area ratios for corroding metals is considered. Graphs.—INCO. 16309

3.6.8

The Mechanism of the Hydrogen-Evolution Reaction on Platinum, Silver, and Tungsten Surfaces in Acid Solutions. J. O'M. Bockris, I. A. Ammar, and A. K. M. S. Hug. J. Phys. Chem. **61,** No. 7, 879-886 (1957).

The parameters of hydrogen evolution were determined as a function of current density, pH, salt addition, mode of electrode preparation, aging and degree of pre-electrolysis. 42 references. —MA. 16142

3.7 Metallurgical Effects

3.7.2, 3.8.4, 6.3.8

Effect of Small Additions of Antimony on Oxidation Velocity of Lead. (In German.) Helmut Hartmann, Wilhelm Hofmann and Wolfgang Stahl. Z. Erzbergbau u. Metallhüttenw., **11,** 151-163 (1958) April.

Preliminary experiments at 350-500 on tarnishing velocity. Gravimetric determination of oxidation velocity at 600 and 750 and explanation of its results according to the scaling theory. Surface tension is dependent on antimony content.—MR. 16060

3.7.2, 3.7.4, 6.2.5

Effect of Boron on Austenite Grain Size in Steel. L. L. Pyatakova and O. D. Zhizhakina. Metalloved. I Obrabotka Metallov, No. 5, 27-30 (1958) May. Translation available from Henry Brutcher, Technical Translations, P. O. Box 157, Altadena, California.

Investigational procedure. Effect of different amounts of boron on austenite grain size of 0.35% carbon cast steel after normalizing at 930 C (1710 F) and on hardenability. Effect of preceding deoxidation with ferrotitanium (subsequent to deoxidation with aluminum) on austenite grain size and grain growth in as-cast and as-forged specimens heated to various temperatures for normalizing. Influence of hot working on temperature of incipient austenite grain coarsening. Explanation of irregularities in grain size as a characteristic of boron steels, especially as-cast. Recommended steps for fine grain in boron-needled steel. 4 figures, 2 tables.—HB. 16109

3.7.2, 3.2.2, 3.7.3, 6.2.5

Study of the Behavior of Steels with 11 to 20 Percent Chromium After Aging in the Range of 475 C Embrittlement. (In German.) E. Baerlecken and H. Fabritius. Stahl und Eisen, **78,** No. 20, 1389-1395 (1958) October 2.

Evaluates the literature on the effects of 11-20 chromium and of other alloying

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elements (carbon, nitrogen, titanium, niobium, molybdenum, silicon, aluminum, manganese and nickel) on the embrittlement of 475 C of chromium steels. Authors then present results of their own hardness, bending and corrosion tests as well as measurements of magnetic saturation carried out on 19 steels containing 0.03-0.105 carbon, 11.0-17.7 chromium, partly with additions of molybdenum and titanium. Annealing at 600 C to restore the 475 embrittlement is considered. Corrosion tests were carried out in boiling nitric acid. Graphs, photomicrographs.—INCO. 17308

3.7.2, 8.8.5

How Alloying Elements Affect Steel Forgeability. G. P. Contractor and W. A. Morgan. Iron Age, **182,** No. 20, 142-146 (1958) Nov. 13; Metal Treatment and Drop Forging, **26,** No. 161, 65-71 (1959) Feb.

Survey of how common alloying elements affect hotworking characteristics of steels. Manganese is essential in steels to reduce the red-short effect of sulfur. In general, it improves the forgeability of carbon steels. This is essential because if the amount of sulfur in one heat is lower than another, less manganese will be utilized in neutralizing the adverse effect of sulfur. Thus its hot-workability will compare with a higher manganese heat. In stainless Type 304 and 321, manganese above 0.40 percent does not appear to improve hot-workability. The opinion is that nickel and manganese tend to have the same or additive effect. So that in lower nickel steels, manganese would be expected to be more effective. In the case of Type 304 and 321, nickel content is already high, restraining the beneficial effect of manganese on forgeability to a limit of about 0.40 percent. Sulfur in relatively large amounts adversely affects the hot-workability of ferrous and non-ferrous materials. When nickel content is kept below 5 percent it tends to improve the hot-twist characteristics of low carbon steels. Pure nickel is ductile at high temperatures. Thus nickel may have a favorable effect on the hot-working properties of steel. But in larger amounts, it appears to reduce hot-workability. This tendency is attributed to the effect of nickel as an austenite stabilizer. Graph shows hot-working properties of Monel. In this case, addition of large amounts of copper has a depressing effect on the forgeability of nickel and nickel alloys. Graphs.—INCO. 17194

3.7.2, 3.7.3, 6.2.5

Effect of Columbium on the Structure of Welds in Austenitic 18-8 Steel. (In Russian.) G. G. Mukhin and N. Yu. Pal'chuk. Avtomat. Svarka, **10,** No. 2, 1-10 (1957). Translation Available from Henry Brutcher, Technical Translations, P. O. Box 157, Altadena, Calif.

Experimental study of effect of niobium present in amounts of from 0.7 to 3.05 per cent upon structure and mechanical properties of austenitic 18-8 welds, as-welded; after tempering; after stabilizing anneal; and after 1000-hr holding at 650 C (1200 F), in part preceded by a quench. Occurrence of a previously unknown phase, the H-phase, in welds with over 2 per cent niobium, after ordinary heat treating or quenching or stabilizing, in addition to niobium carbide, columbide Fe_3Cb_2, and silicide $Fe_4Cb_8Si_3$. Evaluation of results: Effect of niobium on ductility of 18-8 weld metal; conditions under which H-phase is formed and effect of this phase on the impact strength. 6 figures.—HB. 16997

3.7.2, 6.3.5

Oxidation Resistance of a Columbium-Zirconium-Titanium Alloy. G. M. Gordon, J. W. Spretnak and Rudolph Speiser. Ohio State Univ. Trans. Met. Soc. AIME (Am. Inst. Mining & Met. Engrs.), **212,** 659-660 (1958) October.

The oxidation rate in the niobium-zirconium binary system was found to decrease rapidly with increasing zirconium content up to 35 at per cent zirconium. Also, zirconium contents higher than 35 at per cent gave still better resistance to oxidation. Alloys containing 45 to 60 at per cent zirconium exhibited the best oxidation behavior at 1000 C, and their oxide films did not spall upon cooling. The addition of 5 to 10 at per cent titanium to alloys in this range further improved the oxidation rate and the nature of the oxide film formed. The alloy exhibiting the best behavior of those tested (44.5 at per cent niobium, 50.1 at per cent zirconium, 5.4 at per cent titanium) had a very hard and coherent oxide film which was 5 mils thick after 100 hours at temperature. Ternary additions other than titanium to niobium-zirconium alloys may still further enhance the oxidation properties.—NSA. 17407

3.7.2, 6.3.15, 6.3.20, 6.3.9, 6.3.3

Impurities in the Newer Metals: Titanium, Zirconium, Molybdenum and Chromium. D. J. McPherson. Effect of Residual Elements on the Properties of Metals, **1957,** 133-210. Available from the American Society for Metals, 7301 Euclid Ave., Cleveland 3, Ohio.

Present knowledge is summarized. For titanium and zirconium data are given on the effect of impurities on lat-

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tice parameters, resistivity, mechanical properties, tensile and impact properties (titanium alloys being considered) and fatigue behavior. For titanium the effect on stability and some processing procedures are also given; for zirconium the effect on neutron-absorption cross-section and corrosion-resistance. For molybdenum and chromium McPherson discusses the effects on structure and behavior of both interstitial and metallic impurities as well as neutralizers or deoxidizers. 74 references.—MA. 17147

3.8 Miscellaneous Principles

3.8.2, 3.4.7, 3.4.6, 3.6.8

Strain Electrometry, Corrosion and Catalysis. Pt. III: The Iron Electrode. (In English.) A. G. Funk, D. N. Chakravarty, H. Eyring and C. J. Christensen. Z. Phys. Chem., Frankfurt, **15,** No. 1-6, 64-74 (1958) April.

Effects of pH, ferous ion concentration, oxygen and insert gases such as hydrogen and argon, as well as polarization effects on the initial voltages and on the transients induced by straining on iron wire immersed in solution. Results are explaned in terms of known catalytic and corrosive processes occurring at the electrode. Strain electrometry provides a valuable and relatively new approach to the problem of corrosion and catalysis. 15 references.—MR. 17119

3.8.2, 3.6.5, 6.2.2

Corrosion Efficiency in Alternating Current Electrolysis of Iron. (In Japanese with English Summary.) Yutaka Torigoe. J. Electrochem. Soc., Japan **25,** No. 4, 203-208 (1957) April.

Electrolytic corrosion of iron and lead by alternating current has been frequently discussed. However, fundamental studies on the electrochemical behavior have been very few because of the complex corrosion condition.

Fundamental experiments were carried out on the relation between alternating current corrosion and its polarization characteristic, corrosion efficiency current wave shape etc.

1) Sine-waved alternating current electrolysis of iron was conducted in aqueous solution of acidic and neutral salts, and the relation between current density and corrosion efficiency (and generation efficiency of hydrogen gas) was investigated to examine the process of the reaction.

2) Corrosion efficiency in alternating current electrolysis of iron was higher when pH of the electrolytes was lower. The change was confirmed within the range of pH $1 \sim 4$, but the relation of both factors could be explained as based on mutual promotion of delay in every oxidation and reduction of iron and hydrogen.

3) In any electrolyte, when the current density gradually increased and electrode potential reaches the generation potential of oxygen gas, it was confirmed that the neutralization of hydrogen and oxygen began to happen in accordance with the theory of J. W. Shipley.—JSPS. 17075

3.8.2, 3.8.3

Electrochemical Behavior and Anodic Passivity Mechanism of Certain Metals in Electrolyte Solutions. Y. M. Kolotyrkin. Z. Elektrochem., **61,** No. 6/7, 664-669 (1958).

Chromium, nickel and stainless steel (grade 18-8) were studied by the potentiostatic method in a broad range of polarizations. The steady dissolution rate (I_{st}) as a function of the potential for all the investigated metals was found to be expressed by curves similar in shape.—BTR. 17436

3.8.2, 6.3.3

On the Peculiarities of the Anodic Activation of Chromium and Chromium Steels. (In Russian.) A. M. Sukhotin and E. I. Antonovskaya. J. Phys. Chem., USSR (Zhur. Fiz. Khim USSR), **31,** No. 7, 1521-1531 (1957).

The behavior of electrolytic chromium, Nichlome, Armco iron, and steels containing 1-25 per cent chromium was studied in oxidizing solutions under electrolysis. In acid solutions the following processes can occur on the surface of chromium: $Cr \rightarrow Cr^{+3} + 3e$ at 0.74 V.; $2\,Cr + 3H_2O_3 \rightarrow Cr_2O_3 + 6H^+ \pm 6e$ at —0.575 V.; $2\,Cr + 7H_2O \rightarrow Cr_2O_7^{-2} + 14H^+ + 12e$ at 0.295 V.; $Cr_2O_3 + 4H_2O \rightarrow Cr_2O_7^{-2} + 8H^+ + 6e$ at 1.17 V.; $2\,Cr^{+3} + 7H_2O \rightarrow Cr_2O_7^{-2} + 14H^+ + 6e$ at 1.33 V. The order and frequency of various reactions are briefly discussed. 20 references.—MA. 17061

3.8.2, 3.6.5

Electrochemical Mechanisms of Noble-Metal/Hydrogen Systems. Pt. II. Palladium. J. P. Hoare, G. W. Castellan and S. Schuldiner. U. S. Naval Dept., Naval Research Lab. Rept. No. 5129, May 8, 1958, 41 pp. Available from Office of Technical Service, Washington 25, D. C. (Order PB 131683).

Hydrogen producing reactions on a β-palladium cathode were investigated and mechanisms were determined. By means of a palladium bielectrode it was possible to determine mechanisms on anode and cathode surfaces of α-palladium and to study migration of protons through bielectrode. Relation between hydrogen content of palladium and resistance and potential was determined. Equilibrium potential anomalies in palladium/hydrogen system were resolved by showing that potential-determining reaction for α-palladium is an equilibrium between hydrogen ions in solution and hydrogen dissolved in the metal, whereas potential-determining reaction on β-palladium is an equilibrium between hydrogen ions in solution and molecular hydrogen. It was also shown that when palladium is electrolytically charged with hydrogen its electrochemical behavior is different from that of palladium charged by exposure to hydrogen gas. Thermodynamics of these systems are discussed and a structural interpretation of free energy relations is given. Mechanisms of spontaneous solution of hydrogen in + pure palladium in aqueous solution are given. Graphs.—INCO. 17343

3.8.2, 3.6.8

Electrochemical Behavior of Two-Phase Electrodes and the Use of the Overvoltage Curves of These Electrodes in Corrosion Research. (In German.) G. Bianchi and C. Caprioglio. Werkstoffe u. Korrosion, **9,** No. 7, 440-443 (1958) July.

Consideration is given to a two-phase electrode with local-cell formation in the anodic-and cathodic-areas in an external circuit. The polarization potential depends upon: position and magnitude of the local cell areas; anodic and cathodic processes at the local electrodes; direction and strength of the external current; and position of the reference electrode in the solution. Hence current/voltage curves of electrodes, fundamental to corrosion by local currents, can be studied. 10 references.—MA. 17292

3.8.2, 6.2.2

Electrochemical and Corrosion Behavior of Iron in Aqueous Electrolyte Solutions. (In Russian.) Pt. III. Electrode Potential and the Rate of Iron Corrosion in Acid Electrolyte Solutions. B. A. Purin' and L. K. Lepin'. Bull. of the Academy of Science of the Latvian SSR (Latvijas PSR Zinātnu Akad., Véstis), No. 12, 141-150 (1957).

The following electrolytes with the different values of pH were used: hydrochloric acid, hydrochloric acid plus sodium chloride, hydrochloric acid plus calcium chloride and sulfuric acid plus potassium sulfate.—BTR. 16244

3.8.3, 6.2.2

Mechanism of Passivity, Especially in the "Flade" Stress Corrosion of Iron. (In German.) H. Gohr and E. Lange. Z. Elektrochem., **61.,** No. 10, 1291-1301 (1957).

Behavior of active iron and its transition into the passive state. Interpretation of the reduced speed of corrosion of passive iron and its independence of the Fe^{+3} concentration.—BTR. 16184

3.8.3

Protective Films in Passivity. (In German.) U. R. Evans. Z. Elektrochem., **61,** Nos. 6/7, 619-626 (1958).

To determine whether passivity is due to 1) a three-dimensional film 2) a two-dimensional film (chemisorbed material) or 3) a change within the metal or alloy. The evidence supports the idea that a three-dimensional film is usually necessary.—BTR.

3.8.3, 3.6.8, 3.2.2

The Relation Between Pitting Corrosion and the Ferrous-Ferric Oxidation-Reduction Kinetics on Passive Surfaces. Milton Stern. Union Carbide Corp. J. Electrochem. Soc., **104,** No. 10, 600-606 (1957) October.

Ferrous-ferric electrode kinetics have been studied on a variety of passive alloys. Activation polarization parameters are not markedly different for all the surfaces studied except for titanium where the exchange current is an order of magnitude smaller. The local anodic polarization curve for solution of metal under passive conditions was found to be extremely steep. This is suggested as typical behavior for the passive condition. 17150

3.8.3, 3.8.2

Corrosion and Passivity. (In German.) U. F. Franck. Werkstoffe u, Korrosion, **9,** No. 8/9, 504-513 (1958) Aug.-Sept.

Corrosion processes and passivity in metallic materials are of electro-chemical nature. It is possible to show that the passive state is caused by very thin non-metallic films. These films are characterized by certain properties of electric conductivity. Corrosion behavior of passivated metals is governed by the chemical and electric properties of the films and not by the basic metal. 63 references.—MR. 17260

3.8.3, 3.8.4

Sorption, Oxidation and Passivity. (In German.) Norman Hackerman. Z. Elektrochem., **61,** Nos 6/7, 632-637 (1958).

The strikingly large initial effects observed in passivation phenomena are at-

tributed to a temporary change associated with sorption of a suitable specie onto the clean metal in an amount corresponding to about a monolayer. It is agreed that permanent passivity stems from a thin, insoluble film of a compound of the metal but it is suggested that it forms by migration of the metal ion into the array displayed by the sorbed species. It is postulated that the more nearly a complete sorbed monolayer forms before metal ion migration sarts the more likely is the formation of a defect-free, fissure-free compound film. —BTR. 17327

3.8.3, 3.8.4

The Mechanism of Passivation and Surface Film Formation. T. Heumann. (In German.) Archiv. Eisenhüttenw,. **29,** 505-512 (1958) August.

Review of present state of knowledge of passivation and surface-film formation phenomena. Techniques of measuring these, with particular reference to electrochemical methods are given. Formation and decomposition of passivated layers on pure metals, including nickel and iron and behavior of iron-chromium and chromium alloys and chromium steels are discussed. Some data are included on 18/8 steel. Data on effect of alloying additions (nickel, nickel plus molybdenum, nickel plus molybdenum plus copper) on passivation of a 23 per cent chromium steel are given.—INCO. 17372

3.8.3, 4.3.2, 3.6.5, 6.2.5, 6.3.3

Electrochemical Behavior of Passivated Austenitic Nickel-Chromium Steel, Chromium-Molybdenum Steel and Passivated Electrolytic Chromium in Boiling 20% Sulphuric Acid. (In German.) V. Carius. Arch. Eisenhuttenw., **29,** 449-461 (1958) July.

Discussion of redox potential phenomena at passivated electrode. Study of electrochemical and corrosion-chemical behavior of 18-8, 27-2 chromium-molybdenum steel and electrolytic chromium in boiling 20 per cent sulfuric acid was made. Gravimetric and coulometric determination of rate of corrosion with metallographic investigation of specimens was included. Effect of corrosion products on passivity and corrosion at grain boundaries are discussed.—INCO. 17190

4. CORROSIVE ENVIRONMENTS

4.3 Chemicals, Inorganic

4.3.2

The Search for Steels Stable in Sulfuric Acid with Low Nitric Acid Content. E. V. Zotova and A. A. Babakov. J. Applied Chem., USSR (Zhurnal Prikladnoi Khimii), **30,** No. 12, 1795-1799 (1957). Available from Associated Technical Services, Inc., P. O. Box 271, East Orange, New Jersey, U.S.A.

Nitric acid tests performed with 76% sulfuric acid plus 0.05% nitric acid at 130 on steels with varying chromium and nickel and constant molybdenum and copper contents. 3 tables, 1 figure, 2 references.—ATS. 16346

4.3.2, 3.5.9

Corrosion Tests in Hydrofluoric Acid-Water Atmosphere at High Temperature—Negative Results. C. F. Ritchie. Mallinckrodt Chemical Works. U. S. Atomic Energy Commission Pubn., MCW-161, Jan. 12, 1949 (Declassified March 2, 1957), 6 pp. Available from Office of Technical Services, Washington, D. C.

Procedure for testing the corrosion of 29 elements in hydrofluoric acid-water is outlined and results are tabulated. Preliminary tests showed that pure aluminum, copper and manganese were reasonably resistant to hydrofluoric acid-water mixtures at high temperatures.—NSA. 15546

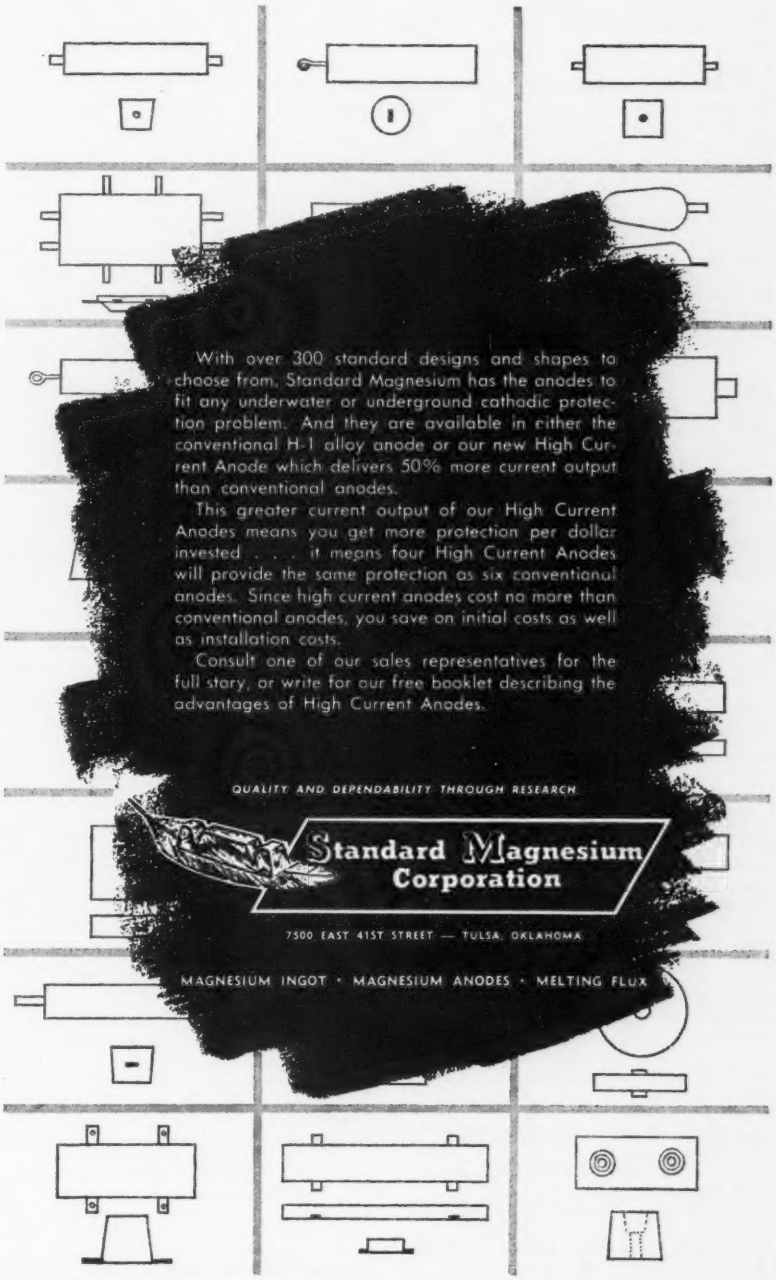
4.3.2, 3.5.9

Semi-Final Report on the Corrosion Resistance of Several Alloys in a hydrofluoric acid-water Atmosphere at High Temperatures. C. F. Ritchie and E. K. Teter Mallinckrodt Chem. Works. U. S. Atomic Energy Commission Pubn., NYO-1309, August 3, 1950 (Declassified March 12, 1957, 7 pp. Available from Office of Technical Services, Washington, D. C.

Macroscopic observations on numerous alloys exposed to a hydrofluoric acid-water atmosphere at 1070 F are given. The most promising metals or alloys that may be used at materials of construction for uranium tetrafluoride process equipment are discussed.—NSA. 16420

4.3.3, 6.2.3, 8.5.3

Corrosion of Mild Steel in Alkaline Pulping Liquors. Pt. 1. Kraft White Liquor. Richard B. Kesler and James F. Bakken. **41,** 97-102 (1958) March.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The effect of the presence of appreciable quantities of sodium chloride, sodium sulfate and sodium carbonate in kraft white liquor on the corrosion rate of mild steel in white liquor. 11 references.—MR. 16546

4.3.2, 6.3.3

Reactions of Metals (Chromium) with Perchloric Acid. (In Serbo-Croatian.) Alksandar M. Lecco, Velimid D. Canic and Jelica D. Misovic. Documenta Chem. Yugoslav., **22,** No. 1, 23-27 (1957).

Metals dissolve in perchloric acid with liberation of hydrogen and formation of the chloride. Chromium forms Cr^{2+}, which is oxidized to Cr^{3+}, the rate of reaction depending on acid concentration, temperature and duration. 60% perchloric acid yields Cr^{3+} at the boiling point; in 65% perchloric acid the bichromate is formed.—MA. 16796

4.3.3, 4.4.7, 7.1

Combustion of Residual Fuel in Gas Turbines. P. T. Sulzer and I. G. Bowen. Conf. on Combustion 1955, **1957,** 386-399. Available from the Institution of Mechanical Engineers, 1 Bird Cage Walk, Westminster S.W.1, England.

Corrosion trials were carried out on various metals exposed to oil ash in a semi-closed-cycle engine and in the engine of an oil tanker. Small tensile specimens were used and penetration rates on these and on descaled specimens are tabulated. Ash contents of vanadium pentoxide, ferric oxide, nickel monoxide and calcium oxide are given. Additives were tried in the tanker engine with an injection system and comparison of runs with and without them are shown with analyses of fuel and blade deposits, the additives were smoke solids, silicon ester, magnesium naphthenate, zinc sulfate and kaolin. Similar data are given for the stationary engine. Additives overcome corrosion, but form powdery layers requiring periodic removal. Volatile solids in oil should be removed, but this problem is unsolved.—MA. 17068

4.3.6, 6.2.5, 6.3.10, 6.4.2, 6.3.6

Corrosion of Some Metals and Alloys in Uranium Hexafluoride. D. Heymann and F. E. T. Kelling. Corrosion Technology, **5,** No. 5, 148-151, 158 (1958) May.

Presents quantitative data on corrosion of aluminum, steels (including 1.7 nickel steel), stainless steels, copper and copper alloys, nickel-aluminum bronzes (Hidurax 1 and 4), Monel, nickel, and titanium alloys in uranium hexafluoride at 80 C. At this temperature uranium hexafluoride is liquefied and its vapor pressure is about 35 psi. Containers were made of copper, brass, 18-8 and Monel, and samples were mounted with Monel wire. Excellent properties of nickel, Monel, copper and aluminum were proved. Ordinary steels were surprisingly resistant to uranium hexafluoride and only addition of chromium will substantially decrease this resistance. Addition of nickel has opposite effect. Stainless steels with high nickel content are excellent. Resistance of titanium alloys is good. Deposit of growth of crystals on surfaces of the various test samples was investigated. Tables.—INCO. 17111

4.3.2, 6.2.5, 3.2.2, 3.7.2

Sulfuric Acid Corrosion of Stainless Steels. W. L. Mathay. U. S. Steel Corp. Ind. and Eng. Chem., **50,** Pt. 1, No. 9, 85A-86A (1958) Sept.

Studies indicate that chromium-nickel austenitic stainless steels are highly resistant to dilute sulfuric acid if proper conditions of temperature, acid concentration and degree of aeration are maintained. Corrosion resistance of these stainless steels depends on maintenance of protective or passive film on surface of metal. Air, or other oxidizing agents in sulfuric acid will extend range of usefulness of austenitic stainless steels and help to ensure their corrosion resistance. Alloy content of austenitic stainsteels influences their performance in sulfuric acid solutions, with the grades having higher alloy content being more resistant. Presence of molybdenum in the alloys is definitely beneficial. A factor that may detrimentally effect behavior of austenitic stainless steels in sulfuric acid is the presence of precipitated carbides at grain boundaries of the metal. If these carbides are present, the metal may corrode intergranularly. Precipitation of carbides occurs when as a result of welding or improper heat treatment, the metal is heated in the temperature range 900-1400 F. Low carbon grades or stabilized grades, AISI Types 321 and 347, are used to avoid intergranular attack. Photomicrographs, diagram.—INCO. 17495

4.3.2, 6.3.17, 1.2.5, 8.4.5

Explosion of EBWR Alloy in Boiling Concentrated Nitric Acid. F. G. Baird, T. A. Gens and L. M. Ferris. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-58-10-43, October 9, 1958, 3 pp. Available from Office of Technical Services, Washington, D. C.

An explosion which occurred while dissolving Experimental Boiling Water Reactor core alloy (93.5 percent-5.07 per cent zirconium-1.5 percent niobium) in boiling concentrated nitric acid is described. (auth).—NSA. 17192

4.3.2, 3.7.3, 6.2.5

Corrosion Characteristics of Welded Seams of Stainless Steels in Oxidizing Solutions. (In Russian.) B. I. Medobar, N. A. Langer and M. M. Kurtepov. Avtomat. Svarka, No. 2, 57-60 (1965).

Tests in boiling 15 per cent nitric acid I), 55 per cent nitric acid II) and 15 per cent solution of nitric acid plus 10 per cent potassium dichromate III), have shown that in I) all the seams tested are stable, in II) the rate of corrosion is 100-200 times higher. In III) a sharp acceleration in corrosion takes place.—MR. 16986

4.3.2, 3.7.4, 6.4.2

Corrosion Along the Boundary of Grains on the Aluminum Surface. (In Japanese.) T. Murakawa. J. Electrochem. Soc., Japan (Denki Kakagu), **25,** No. 8, 427-431 (1957); Chem. Absts., **52,** No. 16, 13595 (1958) August 25.

Seven aluminum samples with purities of 99.73-99.996 per cent were immersed in hydrochloric acid, hydrofluoric acid, hydrochloric acid-hydrofluoric acid, chromium trioxide, and hydrochloric acid-nitric acid-hydrofluoric acid solutions for 12 hours to 10 sec, and the surfaces were observed by a microscope. The area along the boundary of the grains is corroded by hydrochloric acid, while the area a little apart from the boundary towards the center of the grain is corroded by hydrofluoric acid. The relation between the style of the corroded pattern and the distribution of the small amounts of impurities (iron, silicon, copper, etc.) on the aluminum surface was discussed.—ALL. 16999

4.3.2, 6.2.5

Corrosion by Solutions Containing Nitric Acid, Hydrofluoric Acid and Reducing Agents. M. LaVern Holzworth. E. I. Du Pont de Nemours and Co. U. S. Atomic Energy Commission Pubn., DP-284, May, 1958, 24 pp. Available from Office of Technical Services, Washington, D. C.

The corrosion of stainless steel in mixtures of nitric and hydrofluoric acids is markedly increased by the additions of either hydroxylamine nitrate or sulfamic acid, but not by the addition of ascorbic acid. Silver, Hastelloy C and Monel corroded at rates less than five mils per year in a nitric acid-hydrofluoric acid solution containing hydroxylamine nitrate, sulfamic acid, and ascorbic acid. Hastelly B, Haynes 25, Carpenter 20 and Nionel corroded at rates up to 26 mils per year. Corrosion rates of about 25 mils per year were considered acceptable for this application. The corrosion of Type 304L or Type 309Cb stainless steel in a solution of nitric and hydrofluoric acids containing a reducing agent was decreased to less than 20 mils per year by the addition of either aluminum or silver ions. Very small concentrations of either cupric or ferric ions lowered the corrosion rate of 309Cb stainless to less than five mils per year in the same solution. (auth)—NSA. 17451

4.4 Chemicals, Organic

4.4.2, 4.3.6

Corrosion of Copper, Aluminum and Iron in Solutions of Acetic Acid and Ammonium Sulfate. (In Russian.) M. V. Konradi. Izvest. Vysshikh Ucheb. Zazedenii, TSvetnaya Met. (Bull. Inst. Higher Education, Non-Ferrous Met.), No. 4, 165-171 (1958).

Investigation of the corrosion rates of copper, aluminum, iron and their alloys in acetic acid of comparatively low concentration. Determining effect of phenols on the corrosion in acetic acid and investigation of the process in ammonium sulfate solutions at comparatively high temperatures.—BTR. 17428

4.4.7, 3.4.8

New Problems—New Oils. J. V. Kalb. Texas Company. Diesel Power, **36,** No. 8, 24-26 (1958) Aug.

Presents data on development of new lubrication oil for control of wear and corrosion in engines burning heavy residual fuels. Basic problems of burning residual fuels are reviewed: corrosive effects of sodium and vanadium components, high rate of wear of cylinder liners due to high sulfur content, etc. Table giving analyses of fuel oil samples shows nickel content of 16-28 ppm. Data show reduction in wear of cast iron cylinder liner and piston ring with use of Experimental Oil X lubricant. Tables.—INCO. 17394

4.4.8, 6.2.3, 3.4.6

Corrosion of Mild Steel in Aqueous Monoethanolamine. H. R. Froning and J. H. Jones. Pan American Petroleum Corp. Ind. and Eng. Chem., **50,** No. 12, 1737-1738 (1958) Dec.

Monoethanolamine solutions are widely used for removing hydrogen sulfide and carbon dioxide from gaseous streams but severe corrosion has been experienced. Such variables as amine concentration, temperature and composition of acidic gases were studied. Tests were made in glass and stainless steel

vessels. Corrosion rates in stainless steel vessels with 22 mole per cent carbon dioxide in the saturating gas were the highest obtained with fresh amine solution under any test condition. Hydrogen, the only volatile corrosion product identified, was evolved when the saturating gas was nitrogen, carbon dioxide or hydrogen sulfide. Evolution rate decreased with decreasing carbon dioxide concentration and remained high even at low H_2S concentrations. Prime agents of corrosive attack are acidic gases but amine solutions attack mild steel. Graphs, 27 references.—INCO. 17259

4.6 Water and Steam

4.6.1, 5.2.1, 6.2.2, 3.4.7

Corrosion of Iron Covered by Earth. T. Markovic. Werkstoffe u. Korrosion, **9,** 623-630 (1958) October. (In German.)

Research on the influence of water present in soil on electrochemical corrosion of iron. In a slightly acid earth of 3.5 to 4.5 pH, strong rainfall (33 in. yearly) caused corrosion while in an earth of slight basic reaction corrosion decreased with increased rainfall. Cathodic protection best. 11 references.—MR. 17490

4.6.11, 4.3.6, 2.3.4

The Effect of Different Factors on the Rate of Steel Corrosion by Periodic Wetting in Sea Water. (In Russian.) D. M. Abramov. Bull. Acad. Sci. of the Azerbaidzhan. SSSR (Izvest. Akad. Nauk Azerbaidzhan. SSR), No. 8, 31-40 (1957) August.

Steel samples containing 0.1 per cent carbon, 0.36 per cent manganese, 0.018 per cent silicon, 0.017 per cent phosphorus and 0.037 per cent sulfur were exposed to periodic wetting in Caspian Sea water, artificial sea water, distilled water and aqueous salt solutions at 5 to 27 C. The solutions comprised individual or combined concentrations of 8.11 g sodium chloride, 2.945 g magnesium sulfate, 0.983 g calcium sulfate, 0.556 g magnesium chloride, and 0.282 g calcium carbonate per liter of distilled water. Corrosion rates were measured by weight losses after 14 days. During this period, samples were dipped for 30 sec every 2 hr for 8 hr daily; the rest of the time they were kept in air. Some samples were dipped in solutions containing 0.01 to 300 g sodium chloride per liter at intervals of 75 sec to 3 min for 72 hr, and at intermediate intervals of 5 to 60 min.

The corrosion rates varied from 0.084 g per sq m per hr in distilled water at 25 C to 1.583 g in a solution containing 70 g sodium chloride per liter at 18 C. While maximum corrosion occurred in concentrations of 70 g per liter, the greatest acceleration of corrosion rates was found in solutions containing 5 to 10 g per liter. These concentrations are similar to those in Caspian Sea water. Sodium and magnesium chloride solutions were more corrosive than calcium and magnesium sulfate solutions. In solutions combining all these chemicals, the rates were relatively low due to the inhibiting effect of the sulfates. Increases in dipping frequency up to 3 min resulted in higher corrosion rates; at 75 sec to 3 min intervals, the rates were no longer affected. These rates gained momentum in the beginning of the 72 hr. experiments, slowed down rapidly after 1 hr and remained practically constant after 6 hr. Temperature also increased the rate.—PDA. 16977

4.6.2, 7.1, 3.4.3

Observed Effects of Deposits on Steam Turbine Efficiency. J. Angelo and K. C. Cotton. Paper before American Society Mechanical Engineers, Annual Mtg., New York, Dec. 1-6, 1957. ASME Paper No. 57-A-116, 1957, 14 pp.

Presents results of recent tests conducted jointly by electric utility companies and General Electric to show magnitude of deposit problem and to describe testing techniques used. Data were taken on 8 turbines, all of which used solid boiler-feedwater treatment. Units with initial pressures of 1450 psig experience little loss of efficiency due to deposits in steam path; at initial pressures of 1800-2400 psig, there are 3% loss in high-pressure section efficiencies and 1.5% loss in intermediate-section efficiencies due to deposits. Washing or mechanical cleaning of turbines during an outage regains initial efficiency level. Cleaning alone does not eliminate trouble, but improvements made by corrective boiler feedwater treatments are encouraging. Measurement of efficiency of turbine sections operating within superheated-steam section offers accurate and convenient method of determining presence and effect of deposits in steam path.—INCO. 16141

4.7 Molten Metals and Fused Compounds

4.7, 3.8.4, 6.3.10

Forced-Convection Heat-Transfer Characteristics of Molten Flinak Flowing in an Inconel X System. Milton D. Grele and Louis Gedeon. U. S. National Advisory Cttee. Aeronautics, Research Memo. No. E53L18, 1954, 23 pp. (Declassified 1958).

20-foot power-augering equipment operated by CSI.

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181a

Test conditions were: Reynolds numbers 2000-20,000; velocities 4.1-14.7 ft/sec average fluid temperature 1005-1344 F (540-730 C), average surface temperature 1058-1460 F (570-795 C), heat-fluxed up to 400,000 B.Th.U./hr/ft^2. Fluid composition was sodium fluoride-potassium fluoride-lithium fluoride, (11.5, 42.0, 46.5 mole-per cent). The heat-transfer data were ~ 40 per cent of the values given by the McAdams correlation line. Scale formation inside the tube created a high heat-resistance. Intergranular penetration was observed in the test section.—MA. 17397

4.7

Corrosion Resistance of Aluminum Diffusion Coated Cast Iron to Molten Caustic Soda. (In English.) Shigetomo Ueda. Waseda University, Castings Research Lab., Report No. 8, 67-71 (1957) Nov.

Extent and rate of corrosion of mild steel, 17% chromium steel, 18-8 stainless steel, cast iron and aluminum diffusion-coated cast iron exposed repeatedly at 270 to 330 C to molten caustic soda.—MR. 16402

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4.7, 6.2.2

Attack of Iron by Tin-Containing Zinc Melts. (In German.) Dietrich Horstmann. Arch. Eisenhüttenw., **29,** No. 6, 397-400 (1958).

The loss of iron on prolonged immersion in molten zinc is greatly increased by the presence of tin in the bath. Accelerated attack, linear with time, occurs over a range of temperature which is extended and displaced to lower temperature as the tin content increases. In the temperature range where the attack is moderate, and is parabolic with time, the rate of attack depends on diffusion through the Γ phase.—MA. 17388

4.7, 6.3.17

Niobium-Uranium Alloys as Container Material for Molten Uranium Eutectic Alloys. G. W. Powell. Nuclear Metals, Inc. U. S. Atomic Energy Commission Pubn., NMI-1183, August 22, 1957, 20 pp. Available from Office of Technical Services, Washington, D. C.

A previous investigation concerned with liquid-core fuel elements and the materials from which they could be constructed revealed that an alloy of uranium-5 wt per cent niobium had considerable promise as container material. Results are given from a further investigation of this alloy, as well as another containing 10 wt per cent niobium, to determine the time and temperature limits within which the oxide layer remains protective, the factors which hasten or delay the breakdown of the film and the mechanism whereby the film deteriorates. (auth)—NSA. 17053

4.7

Resistance of Metallic Materials to Corrosion Attack by High Temperature Lithium. Interim Report. J. E. Cunningham. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-51-7-135 (Del.), July 23, 1951 (Declassified with Deletions March 8, 1957, 78 pp. Available from Office of Technical Services, Washington, D. C.

Liquid-metal corrosion studies conducted discourage use of lithium as a heat transfer fluid. Data clearly indicate that molten lithium is a more difficult coolant to contain than is the alkali metal sodium. Specific results on the various pure metals tested in an iron capsule under static conditions are that Armco iron, niobium, tantalum, zirconium, uranium and titanium pass good resistance; tungsten limited resistance; and sintered cobalt, vanadium, molybdenum, beryllium, chromium, nickel, manganese and silicon poor resistance to corrosive attack by lithium at 1000 C. At lower temperatures the above metals except for nickel show good corrosion resistance to lithium.—NSA. 15565

5. PREVENTIVE MEASURES

5.4 Non-Metallic Coatings and Paints

5.4.2, 2.3.7, 6.4.2

Vitreous Enamelling of Aluminium Application of Vitreous Enamels on Aluminum. A. H. Symonds. Metal Finishing J., **3,** No. 29, 195-198 (1957) May.

In applying enamel to aluminum the enamel consistency could be adjusted so that with a fine easily controlled spray the enamel readily gives a wet surface. Aluminum enamels are much more prone to contamination troubles than are ferrous enamels, and air-borne dust or contamination with sheet and cast iron enamels cause very serious defects. A special test has been designed for enamel coatings on aluminum, known as the spall test, it determines the retention of adherence at cut or broken edges which simulates conditions where enamel ware may be exposed to weather conditions or high humidity. The test sample has the edges exposed by stoning or cutting. It is then immersed in a 5% solution of ammonium chloride, freshly prepared, at room temperature and left for 24 hours. Upon examination, if there is no spalling to bright metal areas the sample is left for another 96 hours. Failure is usually either very extensive or negligible if correct conditions have been maintained throughout.—ALL. 16295

5.4.5, 8.2.2

Fight Corrosion with Zinc-Rich Paint. J. V. Ferdinand. Industry and Power, **73,** 16-17, 40-42 (1957) Sept.

Describes the parts of a hydro-electric plant in the U.S.A. which have recently been painted with zinc-rich and zinc dust-zinc oxide paints after tests had indicated that they were the most suitable coatings. 5 figures.—ZDA. 16190

5.4.5, 3.4.7

Effect of pH of Metallic Surfaces on the Adhesion of Paints. (In French.) C. Hess. Peint. Pig. Vernis, **33,** No. 9, 798-800 (1957).

The pretreatment of metals for painting is discussed and the importance of a suitable composition for the final painting solution emphasized. This latter should be a mixed solution of phosphoric and chromic acids of pH 3-5.—RPI. 16172

5.4.8, 3.3.4

Effectiveness of Fungicidal Paints. Division of Horticulture Experimental Farms Service, Canada. Plaste u. Kautschuk, **4,** No. 8, 324 (1957).

The prevention of moulds and other micro-organisms in cold storage rooms is discussed, and results with paints containing stated proportions of different fungicides are reported. The best results

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were obtained with diphenyl mercury dodecenyl succinate. More fungicide (e.g., 0.25% instead of 0.1%) is required at room temperature than at 0 C. Paints based on chlorinated rubber without fungicide showed poor resistance to mould growth.—RPI. 16234

5.4.5

New Anticorrosive Bitumen Paints. Pierre Colomb. Zastita Materijala, **6,** No. 7/8, 331-332 (1958) July-August. (In Yugoslavian.)

The author discusses the properties of bituminous coatings without and in the presence of asbestos powder. When a very fine asbestos powder is mixed with bitumen, a single coat of 100-200 μ gives good protection. These paints are thixotropic so that they can be painted on vertical surfaces. They can be applied by spray. The lacquers made from bitumen and some synthetic elastomers can be made to dry in 10-15 min. These lacquers can be used for concrete surfaces immersed in water, or underground. Some new bituminous paints contain red lead or iron pigments and give better protection from industrial atmospheres. The methods of coating oil pipes and sewer pipes are discussed. —RPI. 17222

5.4.5

Red Pigments for Coatings. S. Bonnie. Official Digest Federation Paint and Varnish Production Clubs, **30,** No. 405, 1113-1121 (1958) October.

This article summarizes the properties of red pigments for use in paints. Cadmium selenides and mercurides are included in the section on inorganic pigments and are considered to be excellent for stoving finishes and to have good resistance to alkalis. However, they have a tendency to fade on atmospheric exposure when used in combiination with titanium dioxide in air-drying enamel paints. 3 tables.—ZDA. 17318

5.4.5, 5.9.2, 5.9.3, 8.9.5

Protection of Ships' Bottoms Against Corrosion. O. Thome-Johannesen. Europ. Shipbuild., **6,** No. 5, 117 plus 10 pp. (1957); J. Brit. Shipbuilding R. A., **13,** No. 5, 296-297 (1958).

Surface preparation is the most important factor in the durability of a painting scheme. The two first-class methods of removing mill-scale from ships' plates are pickling and shot-blasting. Some anticorrosive bottom compositions, including bituminous primers, vinyl paints, oleo-resinous types and products based on chlorinated rubber, are described. The number of coats of paints applied has a great effect on the final result. Some application methods are described.—RPI. 17136

5.4.5

Epoxide Enamels for Protection Against Chemical Attack. P. J. Gay. Corrosion Prevention and Control, **5,** No. 6, 75-79 (1958).

For the protection of steelwork and concrete the advantages of using an epoxide enamel cured with polyamide are outlined. When applying this type of finish to a previously painted surface, adequate surface preparation is required and possibly the use of a barrier coat necessary to protect the underlying paint from the action of the solvent in the epoxide enamel.—RPI. 17410

5.4.5

Vinyl/Metal Laminates. R. P. Hooker. Machinery, **93,** No. 2392, 649-653 (1958).

Sheets of vinyl 0.004-0.020 in thick are stuck to sheets of steel, aluminum or magnesium 0.015-0.060 in thick to form a laminate suitable for deep-drawing and mechanical working. These products offer high resistance to abrasion, rust, chemicals and temperatures up to 275 F (130 C). The metal is chemically etched to enhance bonding.—MA. 17374

5.4.5

Effect of Dust Particles on the Electrical Resistance and Anticorrosive Properties of Varnish and Paint Films. C. Graff-Baker. J. Applied Chem., **8,** Pt. 9, 590-597 (1958).

Measurements of the electrical resistance of varnish and paint films indicated that discontinuities were frequently present. The discontinuities arose from the inclusion of dust particles and allowed corrosion of the steel beneath them to be initiated. Varnish films which were prepared with precautions to exclude dust gave exceptionally good protection to steel under immersed conditions and were of much higher electrical resistance than films prepared without these precautions.—RPI. 17404

5.4.5, 8.9.1

Painting Aircraft. M. Larsen. Industrial Finishing, **34,** No. 1, 21+7 pp. (1957).

The process described includes the use of etching-type primers, protective finish coats, sealants, identification markings, camouflage effects, anti-glare strips to

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protect pilot's eyes from sun glare and anti-atomic-flash coatings to protect the belly of a bomber on an atom-bomb run. —RPI. 16216

5.4.8, 4.2.7, 5.6.1

Paints and Packaging for the Tropics. J. Morgner. Plaste u. Kautschuk, **4,** No. 7, 277-280 (1957); **ibid.,** No. 8-9, 323-324, 360-363 (1957).

The German classification of tropical conditions is described and coatings suitable for use with various types of material are discussed. For iron and steel, pretreatment, corrosion protection and the use of metallic aluminum and other pigments for light reflection are described. With light metals, wash primers based on polyvinyl butyral and zinc tetroxychromate, or phosphating, are mainly used. Wood needs protection mainly against biological attacks, and polyvinyl acetate latex paints, with a fungicide, have been valuable in that ventilation of the wood through the film may not be hindered. Electrical insulation lacquers present special problems, because for wire lacquers an operating temperature of up to 155 C may be required. Polyurethane or polyamide lacquers are hardly satisfactory, and the use of terephthalate polyesters has recently shown some success. Special paints for protection against termites and fungi, and packaging methods, including cocoon and strippable films, are also discussed.—RPI. 15879

5.4.5, 8.3.4

Synthetic Resins as Coating Materials in the Wine Industry. D. Manková and J. Janiga. Kvasný Prumysl, **4,** 81-83 (1958); Chem. Absts., **52,** No. 16, 14191b (1958).

Coating materials with chlorinated polyvinyl chloride and an epoxy resin applied on steel tanks, used in the wine industry, were tested. Polyvinyl chloride coatings on fermentation or storage tanks did not prove satisfactory, as they influenced the taste and the aroma of the wine. Good-quality, carefully applied epoxy resin coatings may be used on steel containers. Such containers are suitable only for short-time storage of standard-quality wines. It is necessary to examine the wine in containers during the storage by tasting and also by analyses, especially in relation to the iron content.—RPI. 17500

5.4.7

Flame Spraying of Metals. D. E. J. Cunningham. Corrosion Technology, **5,** No. 3, 71-74 (1958).

Powder and wire guns are described. Corrosion-resistance and some applications of aluminum and zinc coatings and applications of sprayed copper, tin, lead, antimony and cadmium are given.—MA. 17226

5.4.8

Zinc Dust Anti-Corrosive Paints with Electrically Conducting Media. (In German.) M. Kuhn, O. Breier, A. Otto and P. Weidlich. Farbe u. Lack, **63,** No. 11, 535-541 (1957).

An attempt was made to produce primers containing zinc dust in which the electrical conductivity resulted from ionization of the medium rather than metallic contact of the zinc particles. Some conductivity was obtained by modifying alkyd resins with phosphonophenyl-acetic acid, the resins being mixed with basic polyamides and N.C., but details of the anticorrosive performance of the resulting paints are not given. Sulphonamide-modified alkyds were also investigated. In a medium of this type good protection was obtained with 70 parts of zinc dust to 10 of binder; the protective effect of small proportions of zinc dust, mixed with graphite as an electrically conducting extender, was not so good.—RPI. 17008

5.8 Inhibitors and Passivators

5.8.3, 4.3.2

The Action of Corrosion Inhibitors. The Penetrability of Molecular Layers for Hydrogen Ions. (In German.) George Karagounis and Hermann Reis. Z. Elektrochem., **62,** No. 8, 865-870 (1958).

A series of corrosion inhibitors were spread on iron-surfaces in mono- and polymolecular layers and were tested for their protective effect against attack by acid. Based upon the assumption that the molecular intervals are penetrated by H^+ ions, a lattice-like polysulfide of high protective action against acid corrosion was developed.—BTR. 17366

5.8.4

Search for a Substance with Combined Anti-Oxidizing and Corrosion Inhibiting Properties in Relation to Olein and Iron. (In French.) J. P. Sisley, M. Loury and C. Defromont. Revue Française des Corps Gras, **4,** 149-154 (1957) March.

No product now in use in industry combines both properties. Diphenyl-paraphenylenediamine and di-beta-naphtyl-para-phenylenedimine are composed of poly-functional molecules and could be used to develop type of product desired. 7 references—MR. 16826

5.8.4, 1.3

Synthesis and Properties of Pyrazolines. A. N. Kost and V. V. Ershov. (In Russian.) Uspekhi Khim., **27,** No. 4, 431-458 (1958) April.

A review of literature on the synthesis and properties of pyrazolines is presented. The use of 1-phenyl-3, 5, 5-trimethylpyrozoline (U. S. 2,454,075) and 1-thiocarbamido-3, 5, 5-trimethylpyrazoline (V. V. Ershov, Thesis Moscow State University, 1957) as antioxidant additives and corrosion inhibitors in fuels and oils is cited. 227 references. 16882

5.8.4

Corrosion of Shield Tank Materials in Lithium Chromate Solutions. E. Rau and K. Jakobson. Bettis Technical Review, **1958,** 58-65, March; U. S. Atomic Energy Commission Pubn. WAPD-BT-7.

Corrosion of shield tank materials (carbon steel, copper and lead) investi-

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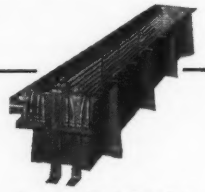

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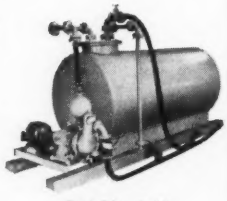

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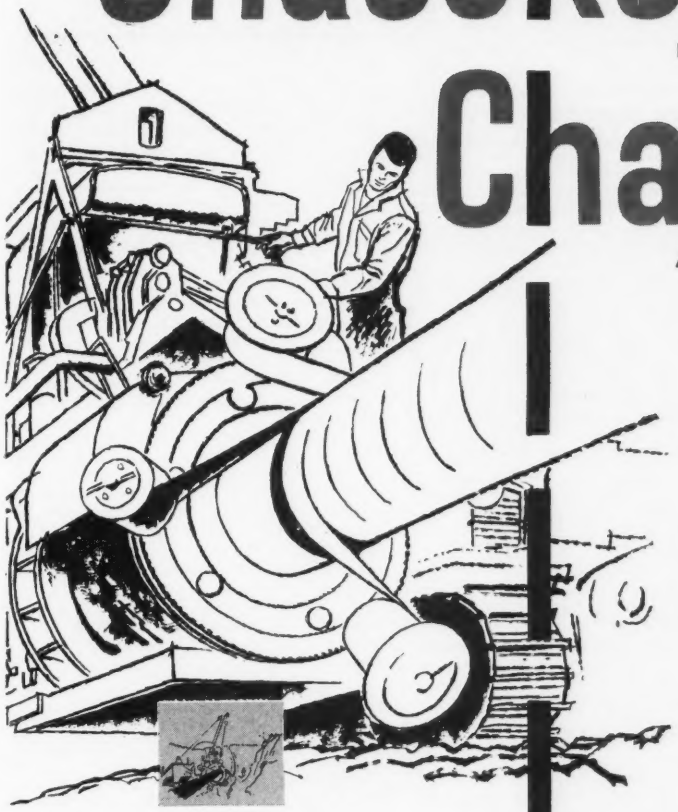

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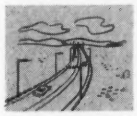

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gated in an inhibiting solution of lithium chromate. Standard test coupons and some soldered couples were tested in lithium chromate solution (1630 ppm) with different pH values. Results indicate that the solution is effective for at least six months.—MR. 16916

5.8.2, 8.4.3

Reduction of Failures Caused by Corrosion in Pumping Wells. T. A. Bertness. Proc. Am. Pet. Inst., **37,** No. 4, 129-135 (1957).

Chemical inhibitors are of value in protecting subsurface equipment only to the extent that they can be placed where they are needed in the quantity and frequency required to do their job. Problems associated with the placement of inhibitors for protection of equipment from an environment of scale and corrosion in pumping wells. Effect of loads on the life of rods; histories of test equipment and well-treating methods. 7 references.—MR. 17030

5.8.3

Cathodic Inhibition by Organic Substances. (In German.) Hellmuth Fischer. Werkstoffe u. Korrosion, **9,** 765-768 (1958) Dec.

Cathodic inhibition, such as by betanaphthaquinoline, N-quinoline ethyl iodide is explained by chemisorption at the double joints of heteocyclic ring shaped compounds. Cathodic anodic inhibition also is assumed. 6 references.—MR. 17250

5.8.2, 4.3.2

Investigation of Corrosion Inhibitors for Fuming Nitric Acid. Period covered November 21, 1955 to June 7, 1957. William H. Bergdorf and Edward J. Kinsey, Jr. Bell Aircraft Corp. U. S. Wright Air Development Center, Technical Report No. 57-302, Sept. 12, 1957, 156 pp. U. S. Atomic Energy Commission Pubn., Contract AF33(616)-3056.

Development of a corrosion inhibitor for fuming nitric acid that has corrosion-inhibiting and scale and sludge-formation properties superior to those of hydrofluoric acid was investigated. Ammonium hexafluorophosphate in amount equivalent to 0.30 per cent by weight hydrofluoric acid was found to provide better inhibition to the corrosion of 61S-T6 aluminum alloy and 17-7 PH and AISI Type 304L stainless steels than 0.70 per cent by weight hydrofluoric acid under the test conditions. Optimum inhibitor concentrations for Types I and III specification acids and inhibitor depletion rates for eight inhibitors including hydrofluoric acid were determined. Effects of inhibitor up to five times optimum inhibitor concentration of each of the several inhibitors were measured in terms of slush or freezing point of inhibited acid media which had been subjected to wide variation in temperature and short time storage conditions. Measurements of the mechanical properties of welded specimens of the aluminum and stainless steel alloys that had been immersed in the liquid and vapor phases of eight inhibited acid systems for thirty days at 120 F showed that no significant change in properties was effected by these exposure conditions. Film-formation studies were conducted on aluminum and stainless steel specimens that had been exposed to the liquid and vapor phases of the several inhibited systems and subsequently rinsed in water and methylene chloride. Both rinses removed the inhibited acids from the specimens, but methylene chloride failed to remove corrosion products. Hydrofluoric acid, phosphoric acid plus hydrofluoric acid, and ammonium hexafluorophosphate at optimum concentrations dissolved in specification Types I and III acid media were tested in vessels fabricated from the aluminum and stainless steel alloys for a period of 60 days at 70, 120 and 160 F. Ammonium hexafluorophosphate produced the greatest pressures during the test period. This inhibitor, however, suffered the smallest loss in concentration and in general provided the best inhibition. (auth)—NSA. 17021

5.9 Surface Treatment

5.9.1, 3.2.2, 6.3.20

Effect of Surface Condition on the Rate of Hydrogen Pickup in Zircaloy-2. A. E. Bibb and A. H. Alberts. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-M-AEB-4, August, 1958, 7 pp. Available from Office of Technical Services, Washington, D. C.

The investigation was designed to determine the effect of various chemical surface conditioning treatments on the relative rate of hydrogen pickup during batch hydriding of Zircaloy-2. (auth). —NSA. 17320

5.9.2

Pickling and Pickling Solutions. Conclusion. (In French.) F. Margival. Peintures, Pigments, Vernis, **34,** 450-459 (1958) October.

Use of emulsified solvents; solutions and procedures for acid cleaning of ferrous metals, copper, aluminum, nickel and their alloys, magnesium, platinum, gold alloys and lead; corrosion inhibition additives; ultrasonic cleaning; rinsing and drying; solutions and procedures for removal of silver, gold, nickel, copper and chromium plate from metal objects. 60 references.—RML. 17488

5.9.2, 6.3.20

Pickling of the Zircaloys Prior to Corrosion Exposure. S. Kass, D. J. Fontanese, A. E. Oaks and D. B. Scott. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-TM-141, Sept., 1958, 65 pp. Available from Office of Technical Services, Washington, D. C.

A series of investigations relative to the pickling of the Zircaloys prior to corrosion exposure is described. The feasibility utilizing common ion neutralization and sulfuric acid rinses subsequent to pickling to facilitate surface cleaning and minimize acid entrapment was investigated. Investigations of various addition agents to the aqueous nitric acid-hydrofluoric acid pickling solutions were made to evaluate pickling rates, surface smoothness, ease in rinsing and effects upon subsequent corrosion properties. The corrosion evaluation of a hydrochloric acid-hydrofluoric acid etchant and nitric and sulfuric acid-hydrofluoric acid solution were made. (auth)—NSA. 17359

5.9.2, 6.4.2

The Influence of Electrolytic and Chemical Polishing on the Corrosion-Resistance of Aluminium. (In Yugoslavian.) Otmar Gautsch. Nova Proizvodnja, **9,** No. 3, 164-167 (1958) June 30.

The article deals with the standard methods of electrolytic and chemical polishing of aluminum. Results of such treatments are evaluated by corrosion tests whereby the rates of corrosion for the various specimens are compared. The experiments seem to indicate that the governing factors in chemical polishing are either the concentration of phosphoric acid in the bath, or, given a constant ratio of sulfuric acid and phosphoric acid, the amount of nitric acid, together with temperature.—ALL. 17099

5.9.4

Chromate Conversion Treatments. Pt. I. D. J. Fishlock. Product Finishing, **11,** No. 11, 53-62 (1958).

The development and application of chromate conversion coatings are described. These coatings offer, relative to their thickness, ease of application and cost, some of the most effective methods available for providing a corrosion-resisting film on a wide variety of metals, particularly zinc and cadmium. 9 references.—RPI. 17268

5.9.4

Effect of Porosity on the Corrosion Rate of Anodic Coatings. (In Russian.) L. I. Kadaner and A. Kh. Masik. Zhur. Priklad. Chem., USSR (J. Applied Chem. USSR), **30,** 839-842 (1957). Translation available from Consultants Bureau, Inc.

The rate of corrosion of anodic coatings in electrolytes depends to a significant extent on their porosity. Increase of the thickness of an anodic coating leads, on one hand, to an increase of the corrosion rate owing to increasing physical heterogeneity, and on the other, to a decrease of the corrosion rate owing to decreased porosity of the coating. The effect of layer thickness on the corrosion rate is determined by the relative significance of these factors. 5 references.—MR. 17001

5.9.4

Here are Advantages of Conversion Coatings. Precision Metal Molding, **15,** No. 12, 54-55, 57 (1957) Dec.

Discusses nature of formation of phosphate and chromate conversion coatings, protection they provide and methods of their application. Electrically inert coating of phosphate crystals overcomes effect of anodic-cathodic differences (electrochemical cells formed by peak, occlusion or stress as shown in diagram), has inherent affinity for paint and locks it to steel base. Chromate film is self-healing if ruptured.—INCO. 16239

5.9.4

Phosphating Processes and Their Applications in Metal Finishing. Pt. IV. Typical Processes. D. J. Fishlock. Product Finishing, **10,** No. 9, 94-104 (1957) Sept.

Deals with practical phosphating applications. Treatment of zinc and cadmium; it is claimed that phosphating is the only sure way to prepare newly galvanized steel for painting. Zinc Flash Bonderizing of strip is described. The author states that phosphating is not beneficial on a sprayed zinc surface, probably due to the porosity of the coating. Other sections deal with the phosphating of threaded parts, spring steels, aluminum and magnesium. 2 tables, 6 figures.—ZDA. 15791

5.9.4, 2.3.7

Phosphating Processes and Their Applications in Metal Finishing. Pt. V.

Process Control. D. J. Fishlock. Product Finishing, **10,** 84-93, 120 (1957) October.

The author advocates both direct control of the phosphating process, by chemical analysis of bath compositions and indirect control, by inspection of the coated article both visually and by determining coating weight, composition, etc. Various performance tests are described. 4 figures.—ZDA. 15792

5.9.4, 5.3.4

Zinc and Phosphate Coatings. N. E. Hays. Industrial Finishing, **9,** No. 110, 757-759 (1957).

The advantages, applications, and properties of hot-dip galvanized or electroplated steel sheet or strip, phosphate-coated at the mill, are discussed with particular reference to Bonderized Armco products.—MA. 15840

5.9.4, 7.6.4

Prevention of Scale and Corrosion With Phosphates and Filming Amines. Corrosion Technology, **5,** 363-364, 368 (1958) Nov.

Phosphate conditioning is now standard practice in boilers working at pressures above 200 psi and has also found use at much lower pressures. Phosphates most commonly used for this treatment are sodium metaphosphate, disodium phosphate and trisodium phosphate.—MR. 17204

5.9.4

Phosphatizing Reactions on Steel. M. Kronstein. S. Kass and J. E. Van Dien. Paint Varnish Production, **47,** No. 12, 46-50 (1957).

Experiments have been made to determine the components of phosphating and chromating solutions becoming part of a phosphated iron surface. After spray application of the phosphate and chromate solutions, and drying for two minutes, the coatings are stripped in a mixed solution of two parts hydrochloric acid and 1 part formaldehyde and the solutions, freed from hydrochloric acid and formaldehyde and subjected to spark discharge in a porous graphite cup for qualitative and quantitative analysis. All components of the treating solutions were found to form part of the metal coating.—RPI. 17137

5.9.4, 6.4.2

Dimensional Changes of Aluminum Alloy Articles in Anodic Oxidation. (In Russian.) A. V. Shreider. J. Applied Chem. USSR (Zhur. Priklad. Chim., USSR.), **30,** 83-93 (1957).

Nature of the dimensional changes is determined by the anodizing conditions and chemical composition and structure of the metal. Dimensional changes are strongly influenced by the method of preparing the surface before anodizing and by the configuration of the anodized articles. For minimum dimensional changes in anodizing for corrosion protection of precision parts, the surface should be prepared by the use of organic solvents (and not alkaline solutions), and the anodic oxidation should be carried out in 3 per cent chromium trioxide solution at 34-44 C at 40 v for 45-60 minutes.—ALL. 17047

5.9.4, 5.3.4, 6.3.15

Electrolytic Oxidation and Galvanic Deposits on Titanium. (In French.) H. Richaud. Rev. met., **54,** 787-792 (1957). Translated by Oak Ridge National Lab., U. S. Atomic Energy Commission Translation No. 3319, Available from the Special Library Assoc. Translation Center, John Crerar Library, 86E. Randolph St., Chicago 1, Illinois.

Various electrolysis factors which can affect the anodic and cathodic treatment of titanium were studied. Experimental results make it possible to prove a relationship between the electrolytic surface treatments of titanium and aluminum. It was found possible to anodically form oxide layers on titanium which increase with time, the increase being more rapid as the current density increases. With respect to the galvanic coatings, the existence of a natural oxide film on titanium necessitates, before the electrolytic deposit, a preparation of a susceptible surface to allow adhesion of the galvanic deposits. The placing of the preparation at the anode and the cathode in an organic chloride solution gives good results.—NSA. 16585

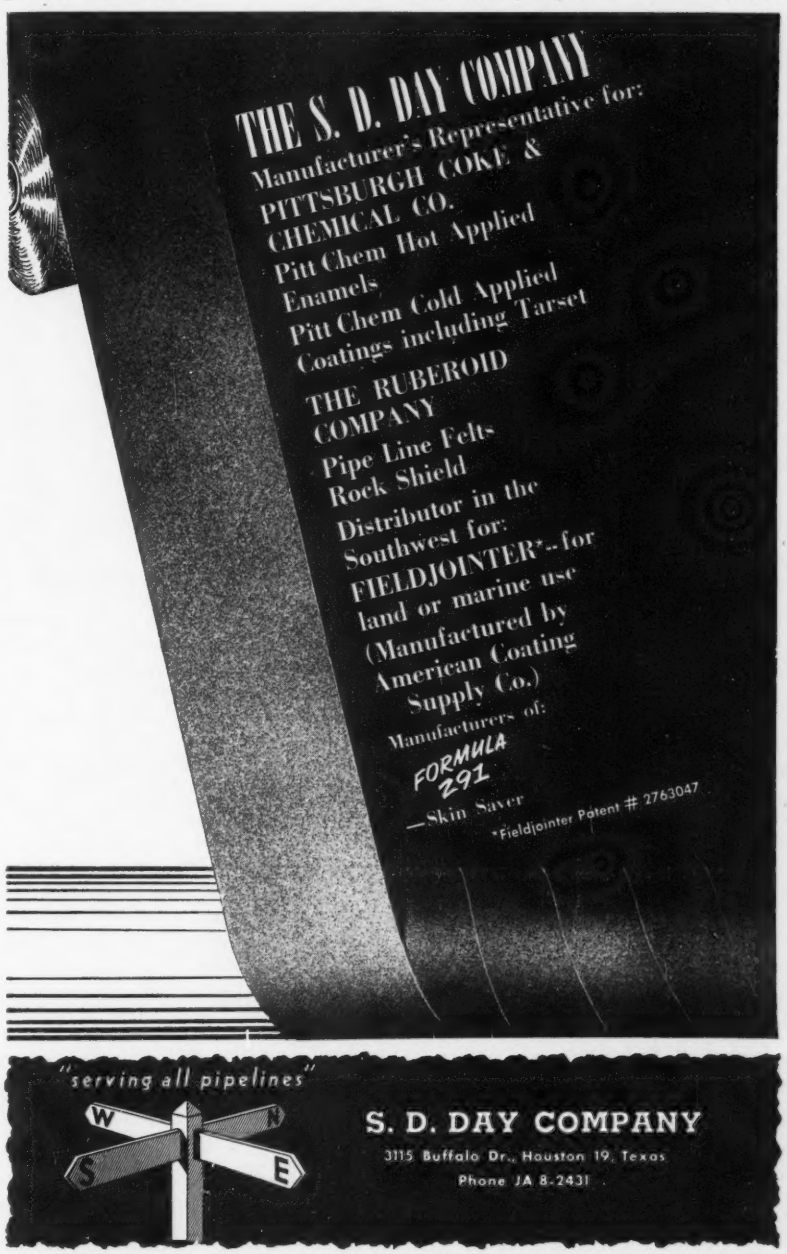
6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.3, 8.8.5

Production of Structural Steels in Arc Furnace with a Very Short Oxidizing Stage. (In Russian.) F. P. Edneral and N. F. Khlystov. Stal, **18,** No. 1, 43-48 (1958).

Investigation of possibility of shortening oxidizing period by one third if a stated amount of lime is added to charge and if a stated volume of oxygen per ton of steel is blown through bath at end of meltdown, thus ensuring fairly complete dephosphorization. Steel used in tests was 45KhNMFA (0.42-0.50 carbon, 0.50-0.80 manganese, 0.17-0.37 silicon, 0.03 phosphorus maximum, 0.03



sulfur maximum, 0.08-1.10 chromium, 1.30-1.80 nickel, 0.20-0.30 molybdenum and 0.10-0.20 vanadium). Graphs.—INCO. 17272

6.2.4

"Kai-Speed": New Free-Machining Steel is Developed in the West. F. S. Jacobson. Kaiser Steel Corp. Western Machinery and Steel World, **49,** No. 8, 54-56 (1958) August; Western Metalworking, **16,** No. 7, 39 (1958) July.

Production studies and tests demonstrated that steel with following composition has outstanding machinability: 0.08 maximum carbon, 0.85-1.20 manganese, 0.07-0.12 phosphorus, 0.35-0.44 sulfur and 0.01 maximum silicon. It is control of carbon and silicon within narrow limits, benefits of extra-high sulfur, and careful attention to open-hearth practice and mill processing that make Kai-Speed a super free-machining steel. Tables, graphs.—INCO. 17110

6.2.4, 3.5.9

Consider Chromium-Molybdenum-Vanadium Low Alloy Steels for 1000 F Service. C. M. Cosman. Vanadium Corp. of America. Materials in Design Eng., **48,** No. 4, 93-96 (1958) October.

Demands for industrial equipment to operate economically at ever increasing temperatures and pressures have led to development of low alloy steels. Experimental work has shown that adding vanadium to chromium-molybdenum steels improves high temperature properties. Comparison is given of long-time properties of chromium-molybdenum-vanadium and other low alloy stees. Chromium-molybdenum-vanadium steels should be considered not only for power plant service, but also for applications in chemical and petroleum industries in 950-1100 F range under conditions in which corrosion is not a major problem. In high temperature castings of chromium-molybdenum-vanadium or chromium-molybdenum types, nickel was believed to favor embrittlement. However, smooth and notched test pieces of nickel-containing chromium-molybdenum and chromium-molybdenum-vanadium steels were tested at 1020 F. Test ran up to 20,000 hr. without showing any unfavorable effect from nickel content in a range of 0.5-1 nickel. Graphs, tables.—INCO. 17203

6.2.5

Corrosion Resistance of Austenitic Nickel-Chromium Steels. W. Katz. Nickel Information Bureau, Dusseldorf. Draht (English edition), No. 36, 27-31 (1958) Aug.

Reviews passivity and corrosion, effects of alloy components, composition of the passive layer and forms of corrosion which may be found with stainless steels; summarizes behavior of austenitic stainless steels in contact with: atmosphere, water, salts, acid, alkalis and organic substances. Table compares nickel-chromium steels in accordance with German (4000 series), American (300 series) and British (En series) standards. 20 references.—INCO. 17360

6.2.5, 7.6.4, 4.6.2, 3.5.8

Investigation of Suitability of 18-8 (Type 304) Alloy for Superheater Service With Respect to Corrosion and Stress-Corrosion Behavior in Chloride-Bearing Steam Condensate. F. B. Snyder, T. A. McNary and F. Eberle. Paper before Am. Soc. Mechanical Engrs., Annual Mtg., New York, December 1-6, 1957. ASME Paper No. 57-A-174, 1957, 17 pp.

Investigation of possibility of using nonstabilized 18-chromium-8 nickel type alloys as high-temperature superheater materials in place of the present practice of using stabilized 18-8 materials. Comparative corrosion tests in synthetic steam condensates containing 38.4- and 2000- ppm chloride have shown that nonstabilized alloys, like stabilized alloys, are not subject to inter-crystalline corrosion attack in these media. Stress-corrosion tests in same media showed that both stabilized and nonstabilized alloys suffered stress-corrosion cracking. No significant difference was observed in this respect between the two types of materials. In addition, nonstabilized 18-8 (Type 304) tubing, when installed in pendant superheater of an operating stationary boiler, showed no intercrystalline corrosion attack after up to 54 months service. Tables, graphs, photographs, numerous photomicrographs.—INCO. 16291

6.2.5, 4.3.2

The Corrosion-Testing of Stainless Steels in Liquids. (In German.) H. Zitter. Werkstoffe u. Korrosion, **8,** 746-760 (1957) Dec.

Details of laboratory tests for determining corrosion behavior of nickel-chromium, nickel-chromium-molybdenum, nickel-chromium-copper-molybdenum and chromium stainless steels in liquid media. Effects of heat-treatment of material, interruption of test and agitation are discussed. Supporting data are given on steels exposed to nitric acid, hydrochloric acid and sulfuric acid.—INCO. 16356

6.2.5, 1.3

Materials of Construction—Stainless Steels Including Other Ferrous Alloys. W. A. Luce. Duriron Co. Inc. Ind. and Eng. Chem., **49,** No. 9, Pt. 2, 1643-1652 (1957) September.

Annual review of literature covers corrosion, mechanical properties, structure, high temperature, welding, manufacture, metal working, surface treatment and miscellaneous iron-base alloys (high-silicon iron, iron-nickel alloys, and austenitic iron-manganese steel). 137 references.—INCO. (15828

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.15

Electrochemical Investigations of Pure Titanium and of Alloy TiMo30. (In German.) O. Rudiger and R. W. Fischer. Tech. Mitt. Krupp, **15,** No. 7, 194-202 (1957) Dec.

Corrosion resistance of titanium is result of the titanium dioxide-titanium hydride layer. Measurement of potential provides the means of studying formation and dissolution of protective layers. 10 references.—MR. 16310

6.3.20

Mechanical Properties of Iodide Zirconium Alloys. A. D. Schwope and W. Chubb. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-780 (Del.), November 1, 1952 (Declassified with Deletions May 7, 1957), 21 pp. Available from Office of Technical Services, Washington, D. C.

The tensile properties, hot hardness, impact strength and corrosion resistance of some arc-melted iodide zirconium alloys were determined. The alloys investigated include binary alloys of zirconium containing zero to 5% tin and zero to 0.14% nitrogen and ternary alloys of zirconium containing tin and nitrogen, tin and uranium, uranium and beryllium. (auth)—NSA. 16320

6.3.20, 4.6.2

Zirconium Progress Report for the Period of March 15-June 15, 1954. Northwest Electrodevelopment Lab. U. S. Atomic Energy Commission Pubn., BM-II-90, July 9, 1954 (Declassified Feb. 12, 1957), 36 pp. Available from Office of Technical Services, Washington, D. C.

The production of hafnium and zirconium and improvement in the yields and reclamation of scrap are reported. Studies were made on the corrosion of zirconium and zirconium alloys in water at 600 to 1000 F and steam at 750 F and the effects of the addition of metals on the corrosion resistance. A summary of the results in the study of derived high-purity concentrates of zirconium minerals is given.—NSA. 16265

6.3.20, 3.2.2

Hydrogen Pickup During Corrosion Testing of Zirconium and Zircaloy-2. K. M. Goldman and D. E. Thomas. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-MM-184, Feb. 19, 1953 (Declassified March 21, 1957), 13 pp. Available from Office of Technical Services, Washington, D. C.

Tabulated data are presented from a study on the rate of hydrogen pickup during corrosion testing of arc-melted sponge zirconium and zircaloy-2 as a function of thickness, hydrogen content of the water, and initial hydrogen content of the metal. The testing temperature was 600 F. Hydrogen contents were measured in specimens after removal from corrosion test without any subsequent surface preparation.—NSA. 15798

6.3.17, 3.8.4

Surface Oxide Films and the Breakaway Corrosion of Uranium. J. S. Llewelyn Leach. Imperial Coll., London. Nature, **182,** 1085-1086 (1958) October 18.

Preliminary results are reported from a study of the protective effects of surface oxide films against the corrosion of uranium. By measuring the electrical and leakage resistance, an estimate is made of the thickness and conductivity of the oxide film. The influence of the properties of the surface film on breakaway corrosion of uranium is discussed.—NSA. 17458

6.3.20, 3.7.4

Progress in the Resolution of Anomalous Zirconium Alloy Corrosion Problems. J. G. Goodwin and E. L. Richards. Bettis Technical Review, **1,** No. 2, 59-70 (1957) July; U. S. Atomic Energy Comm., WAPD-BT-2.

Studies show that corrosion properties of zirconium alloys have been definitely related to microstructure and work is under way to incorporate this knowledge to produce corrosion resistant material. In so doing, it may be possible to relate welding and mechanical properties to microstructure and possibly eliminate unsolved problems which have not had a metallurgical basis for solution. A complete understanding of melting and fabrication variables on zirconium alloys is required, particularly when melting of large ingots is being contemplated. Photomicrographs, photos.—INCO. 17017

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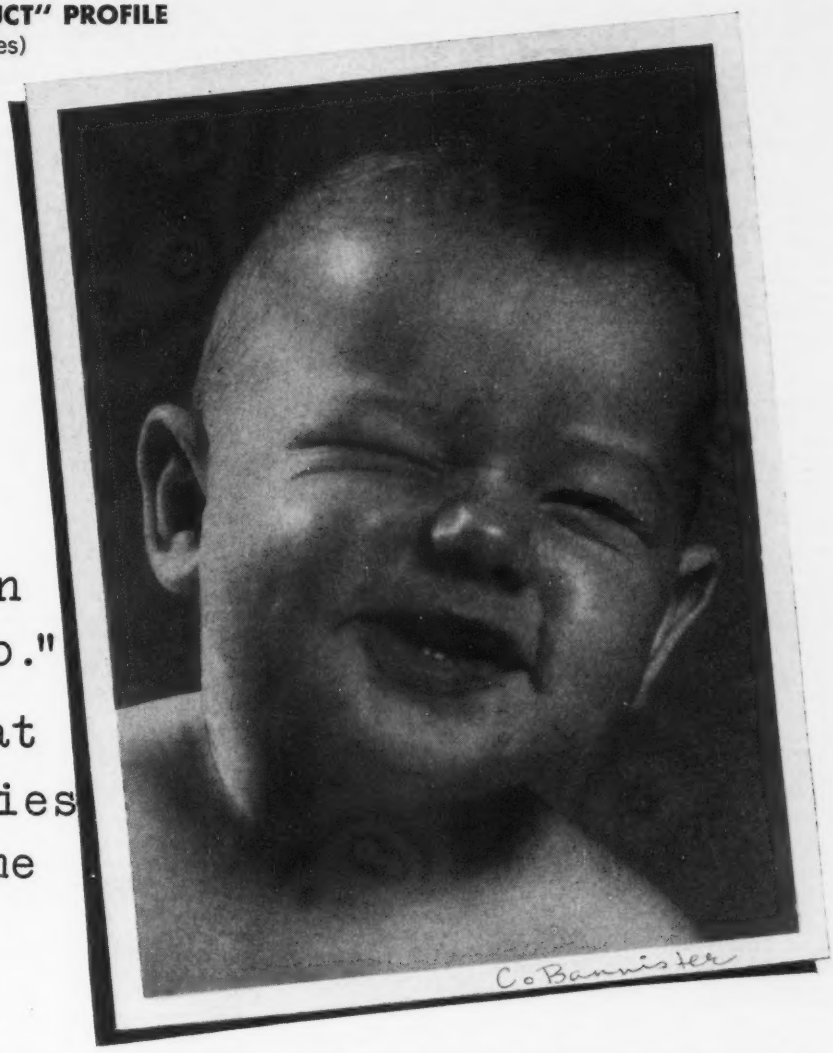

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6.3.20, 4.6.1

The Chemical Reaction of Zirconium-Uranium Alloys and Water at High Temperatures. William N. Lorentz. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-PM-22(Del.), July, 1955 (Declassified with Deletions August 13, 1958), 32 pp. Available from Office of Technical Services, Washington, D. C.

Rapid self-sustaining reactions between Zr-U^{235} alloy and water did not occur below the melting point of zirconium in tests performed to define conditions under which such a chemical reaction would occur. Above the melting point of zirconium the reaction proceeds very rapidly but not explosively.—NSA. 17464

6.3.17, 8.4.5

Advances in the Physical Metallurgy of Uranium and Its Alloys. H. H. Chiswik, A. E. Dwight, L. T. Lloyd, M. V. Nevitt and S. T. Zegler. Argonne National Lab. U. S. Atomic Energy Commission Pubn., A/Conf.15/P/713, 35 pp. Prepared for the Second U. N. Internation Conference on the Peaceful Uses of Atomic Energy, 1958. Available from Office of Technical Services, Washington, D. C.

A general survey is presented of information in the unarium alloy field. Emphasis is centered on alpha uranium-rich alloys of special interest as uranium-base fuel element materials. The systems treated include uranium-molybdenum, uranium-silicon, uranium-zirconium, uranium-niobium and uranium-zirconium-niobium (high uranium compositions). The uranium-fissium alloys are discussed in relation to their projected applications as fast reactor fuels. Equilibrium diagrams, transformation kinetics and other pertinent data are presented for the uranium plus "fissium" element systems, e.g., uranium-ruthenium, uranium-rhodium, uranium-palladium and uranium-molybdenum-ruthenium. The properties covered include constitution phase diagrams, metallographic structure, physical and mechanical properties, transformation kinetics, crystallographic structure, thermal cycling and irradiation stability (where pertinent). Correlations between microstructure, heat treatment and dimensional stability are emphasized, with particular reference to the uranium-2 wt.% zirconum, uranium-5 wt.% zirconium, and 1½ wt.% niobium alloys. A discussion of the role of alloying and heat-treatment in improving the dimensional stability and corrosion resistance of uranium is presented and an evaluation is made of the present status in attaining these objectives. (auth)—NSA. 16976

6.3.20, 8.8.5, 4.6.2

The Relative Corrosion Resistance of Zircaloy 2 Made From Electrolytic Zirconium Powder and That of the Corresponding Alloy Made from Kroll Process Sponge. M. D. Carver and E. T. Hayes. Bureau of Mines, U. S. Atomic Energy Commission Pubn., USBM-U-43, July 22, 1955 (Changed from Official Use Only August 28, 1958), 8 pp. Available from Office of Technical Services, Washington, D. C.

To determine the corrosion resistance of specimens of Zircaloy-2 made from electrolytic zirconium powder relative to that for the corresponding alloy made from Kroll Process sponge, corrosion specimens made from each of five lots of powder were tested both in high-temperature water and in steam. Corrosion data were compared to those for specimens from production lots, made from sponge, tested concurrently. Samples of the sheet from each of the lots of powder were subjected to chemical analysis and the results were compared to the specification limits of the specification governing the production of Zircaloy-2. The amounts of the impurities aluminum, nitrogen and titanium, elements known to adversely affect corrosion resistance of Zircaloy-2, were found to be high. Corrosion resistance of Zircaloy-2 made from the powder was found to be much lower than that of the corresponding alloy made from sponge. (auth).—NSA. 17187

6.3.20, 3.8.4

Some Qualitative Observations of Zirconium-Water Reactions. D. C. Layman and H. L. Mars. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-1534, April 23, 1956 (Declassified April 11, 1957), 23 pp. Available from Office of Technical Services, Washington, D. C.

Self-sustaining and self-propagating chemical reactions between Zircaloy and water have been demonstrated. High-speed motion pictures illustrating the phenomena involved have been made. Qualitative results of a test program limited to experiments at atmospheric pressure, stagnation and at temperatures in the subcooled range from 40 to 150 F are presented. Samples were heated by electrical power inputs of increasing exponential periods in the range of 2 to 20 msec. The chemical reaction was initiated very close to the melting point of Zircaloy, proceeded with varying rates and sustained itself to complete loss of sample in some cases. The reaction showed the characteristics of a combustion process rather than an explosion. The hypothesis is advanced that the rate of the chemical reaction is dictated by the rate of diffusion of the reactants into a reacting zone and that temperature sensitivity is not the rate-controlling parameter. (auth)—NSA. 15959

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2, 4.6.5

Aluminum Corrosion-High-Purity Water. N. A. Nielsen. E. I. du Pont de Nemours. U. S. Atomic Energy Commission Pubn., DP-6 (Del.), May, 1952 (Declassified with Deletions Feb. 15, 1957), 7 pp. Available from Office of Technical Services, Washington, D. C.

A section of a 63S aluminum fuel tube with 2S and 43S and Type 304 stainless steel components exposed to water of high specific resistivity for four weeks did not show any corrosion pitting or abnormal corrosion. The test was carried out under conditions designed to simulate plant geometry and service conditions, such as water purity, temperature, and flow rate. (auth)—NSA. 15865

6.4.2, 3.5.4, 4.6.2

Surface Structure of Pile Irradiated 2S Aluminum. D. Borasky and B. Mastel. Hanford Atomic Products Operation. U. S. Atomic Energy Commission Pubn., HW-37049, August 1, 1955 (Declassified Feb. 7, 1957), 24 pp. Available from Office of Technical Services, Washington, D. C.

The surfaces of cold rolled, half hard, nitric acid treated, autoclave etched, 2S aluminum coupons were studied by optical and electronoscopic methods, before and after exposure to hot water alone and hot water and neutron bombardment. The non-exposed aluminum surfaces have a characteristic etch pattern which is absent in the exposed coupons. All of the exposed coupons were corroded. In general the coupons exposed to the higher flux intensities of irradiation were more severely corroded than those exposed to the lower flux intensities of irradiation or to the hot water alone. Representative photo- and electron micrographs illustrate the various types of surface structure observed on the control and experimental coupons. (auth)—NSA. 15725

6.4.4, 3.7.2, 3.5.8

The Relationship Between the Structure of Some Magnesium Alloys and Their Tendency to Corrosion Under Stress. (In Russian.) M. A. Timonova. Proc. Acad. Sci., USSR (Doklady Akad. Nauk, SSSR), **117,** No. 5, 848-851 (1957) Oct. 11.

The main element which causes corrosion cracking of magnesium-aluminum-zinc-manganese alloys is aluminum when more than 2 to 3% is present.—BTR. 16366

6.4.2, 3.7.2, 4.6.11, 3.6.5, 3.8.3

Protective Characteristics of Aluminium Alloys with Elements of the Second Group of the Periodic System. (In Russian.) A. L. Seifer. Uchenye Zapiski Azerbaidzan. Gosudarst. Univ. im. S. M. Kirova, (USSR), No. 1, 39-53 (1957); Chem. Absts., **52,** No. 17, 14492-14493 (1958) Sept. 10.

The protective characteristics of binary and ternary aluminum alloys with lithium, beryllium, magnesium, calcium, strontium, barium, zinc and cadmium were investigated in Caspian Sea water, in 0.5N sodium chloride and 0.5N sodium sulfate at 20 ± 2 C. The aluminum content of the alloys was not less than 75-80 percent. The protective properties were considered as a function of the initial electrode potential, the anodic characteristics and the actual current output at an anodic current density of 21 ma/sq dm. The addition of lithium, magnesium, calcium, strontium and barium caused a change of the initial electrode potential of aluminum in sea water and in 0.5N sodium chloride towards more negative values. The anodic polarization of alloys with elements of the calcium group was determined by the dissolution of the protective oxide film by the products of corrosion (OH^-ions). In solutions of sodium sulfate the anodic polarization of the same alloys was even more pronounced. In this case the protective film was not destroyed but reinforced owing to the formation of scarcely soluble sulfates of calcium, strontium and barium on the surface of the metal. The addition of 5 percent zinc decreased the electrode potential and the anodic polarization. Of all binary aluminum alloys only those with 1.94 percent barium and 5.0 percent zinc had a protective capability against sea-water corrosion owing to their more negative electrode potential than that of steel. The property of zinc to activate the protective film on aluminum alloys was also preserved in ternary alloys with lithium, magnesium, or an element of the calcium group as the third component. In addition, each of the three elements contributed to the electronegative character of the alloys. Cadmium was even more capable than zinc to activate the protective film.

Therefore, such ternary alloys as aluminum-cadmium-magnesium and aluminum-cadmium-lithium in sea water or sodium chloride solution had more negative electrode potentials than analogous zinc alloys. The actual current output varied from 2100 to 2500 amp hrs/kg of protector (in sea water at current density of 21 mg/sq dm) for the binary alloy aluminum-barium and for the following ternary alloys: aluminum-zinc-lithium, aluminum-zinc-magnesium, aluminum-zinc-calcium, aluminum-zinc-strontium, aluminum-zinc-barium, aluminum-cadmium-lithium and aluminum-cadmium-magnesium. Most of the latter were recommended for protection against seawater and soil corrosion.—ALL. 17059

6.4.2, 3.6.6, 2.2.2

The Behaviour of Aluminium and Its Alloys in Various Atmospheres, Part I. (In French.) André Guilhaudis. Rev. Aluminium, **35,** No. 259, 1111-1118 (1958) November.

In this first installment of a series of articles on the atmospheric and contact corrosion of aluminum alloys several open-air corrosion testing stations in metropolitan France and also in the Colonies are described and test results concerning bimetallic assemblies are reported. The behavior of various aluminum alloys in contact with iron, steel and brass fasteners and the protective value of coatings of different types is studied. Aluminum-5 per cent magnesium alloy, a material widely used in shipbuilding is said to have excellent corrosion-resistance, unless as a result of a special structural condition, it has developed susceptibility to intergranular corrosion.—ALL. 17405

6.4.4, 3.6.6, 5.3.4, 5.9.2, 5.4.5

Three Ways to Avoid Corrosion in Magnesium. R. J. Fabian and J. Stevens. Dow Chemical Co. Materials in Design Eng., **48,** No. 7, 109-111 (1958) Dec.

Discusses protection of magnesium surface by surface treatments, paints, primers and plating. Compatible materials should be used wherever possible. Metals that tend to corrode magnesium when coupled to it under corrosive conditions are carbon and alloy steels, stainless steels, titanium, brass, copper, Monel and some aluminum alloys. Careful attention to joint design and selection of fastener materials is essential in preventing corrosion of magnesium. Steel and copper rivets, as well as steel, nickel, aluminum and brass bolts and screws should not be used directly against magnesium. In general, a tin, zinc or cadmium plate on these parts is recommended, followed by a chemical treatment plus an alkali resistant epoxy or vinyl coating. Diagrams.—INCO. 17249

6.6 Non-Metallic Materials

6.6.6, 4.7

Behavior of Ceramic Materials in a Corrosive Superheated Boron Oxide-Boron Environment. Period Covered: January 1957 to August 1957. H. F. Rizzo, B. C. Weber and M. A. Schwartz. U. S. Wright Air Development Center. Technical Rept. No. 57-525, August, 1957, 112 pp. Available from WADC, Aeronautical Research Lab., Wright-Patterson AFB, Ohio.

The behavior of a number of ceramic materials in a boron oxide-boron corrosive environment at 1100 to 1315 C is described. Such variables as melt composition and time and temperature of exposure were employed to study the kinetics and reaction mechanisms. A new material, consisting essentially of a silicon plus boron composite, was determined to possess high resistance to the corrosive medium. This new material possessea a high degree of stability in air, under the test conditions employed and an apparent high strength and thermal shock resistance. (auth)—NSA. 17078

6.6.6, 3.4.9, 3.5.8, 3.7.4

Static Fatigue of Glass. Pts. I and II. R. J. Charles. Gen. Elec. Res. Lab. J. Applied Phys., **29,** No. 11, 1549-1553; 1554-1560 (1958) Nov.

Water vapor corrosion of simple soda-lime glass was studied in regard to its effect on static fatigue of the glass. Mechanism of dissolution is proposed in which alkali ion self-diffusion controls initial steps of water corrosion and leads to breakdown of glass network. Since experiments show that expansion of glass network enhances corrosion rate, it is postulated that asymmetrical conditions of expansion around surface flaw, brought about by applied stress, could lead to growth of flaw in preferential direction to bring about delayed failure. Part 2 presents an experimental analysis of such a delayed failure. Graphs.—INCO. 17233

6.6.6, 3.5.9, 2.1.1

Reproducibility of the Mechanical Properties of Ceramic Materials. Part II. Thermal Shock Resistance of High Purity Alumina Specimens. N. R. Wheelock and C. A. Liedholm. Curtis-Wright Corp. U. S. Atomic Energy

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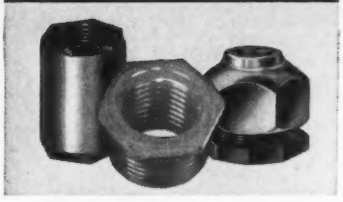

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Commission Pubn., CWR-481, August 19, 1957, 16 pp. Available from Office of Technical Services, Washington, D. C.

This report is the second in a series concerning the reproducibility of the properties of ceramic materials. Previous work, reported in CWR-456 (Ref. 1) concluded that the modulus of rupture of a batch of high purity alumina specimens was in statistical control, making it possible to estimate the probability of failure associated with any arbitrarily selected load. The present report concerns the thermal shock strength of specimens of a similar material. The experimental data obtained agreed well with the assumption that thermal shock strength also was a statistical control, so that the probability of failure could be estimated for cooling in still air from any arbitrarily selected uniform heating temperature. (auth)—NSA. 16375

6.6.6, 4.3.2, 3.7.3

Observations on the Physical Appearance of Chemically Attacked Glassed Steel Surfaces. D. K. Priest. Paper before Am. Ceram. Soc., 59th Annual Mtg., Dallas, May 7, 1957. Ceram. Bull., **36**, No. 11, 416-418 (1957) Nov.

Glassed steel corrosion specimens made using various frit sizes of borosilicate glass were subjected to action of vapor of boiling 20% hydrochloric acid. Attack occurs preferentially at joining lines of fused particles of glass frit. Some preferential attack occurs within glass frit particles. Nature and extent of attack changes with fusion firing time. Corrosion test apparatus is described. Photomicrographs, tables of corrosion rates.—INCO. 16271

6.6.6, 5.3.4

Ceramic Reinforced Alloys and Plated Cermets. M. T. Curran and others. The New York State College of Ceramics for U. S. Wright Air Development Center, U. S. Air Force, May, 1957, 49 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131188).

A precision technique was developed for casting super alloys around ceramic rod reinforcement. Although the reinforced alloy had somewhat lower stress rupture life at 1800 F, than the alloy itself, there was indication that the ceramic contributed considerably to a decrease in deformation. Procedures were found for the electroplating of cermets with nickel and chromium to improve their impact resistance and for the chemical plating of nickel on titanium carbide grains. The effect of molybdenum as an alloying agent in the cermet binder was also observed.—OTS. 15566

8. INDUSTRIES

8.4 Group 4

8.4.5

Development of a Composite Control Rod. G. W. Cunningham, A. K. Foulds, D. L. Keller and W. E. Ray. Nuclear Sci. and Eng., **4**, 449-457 (1958) Sept.

The scarcity and high cost of hafnium for use as a reactor control material has lead to the development of a composite control rod of hafnium and B^{10}. The fabrication technique developed involves the use of a wrought hafnium and a 3.5 wt. percent B^{10} dispersion in titanium powder. The two components are placed end to end and clad with titanium by a roll bonding technique involving the use of a restraintive stainless steel rolling frame to control the differences in ductility of the two control materials. These composite control rods have been evaluated by bend and tensile testing, thermal cycling, corrosion testing in high-temperature water, control worth, and information gathered on the resistance of the materials to irradiation damage. Favorable results were obtained from the evaluation study. (auth).—NSA. 17217

8.4.5

Broad Aspects of Absorber Materials Selection for Reactor Control. W. K. Anderson. Knolls Atomic Power Lab. Nuclear Sci. and Eng., **4**, 357-372 (1958) Sept.

The selection of materials for control of nuclear reactors employing a variety of coolants and working over a broad range of neutron spectra are considered from a qualitative standpoint. The materials discussed include hafnium, boron, cadmium, indium, silver, europium, gadolinium and samarium. A basis for selection of materials is presented which should permit control of practically any reactor proposed today with a minimum of additional development. Materials are discussed from the standpoint of nuclear acceptability, metallurgical fabricability, corrosion resistance, radiation damage resistance, economics and probable contributions to the over-all radioactivity problem. (auth).—NSA. 17317

8.4.5

Corrosion of Some Reactor Structural Materials at 600 F. B. G. Schultz and P. Cohen. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-RM-194, Sept. 28, 1953 (Declassified March 7, 1957), 14 pp. Available from Office of Technical Services, Washington, D. C.

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Results are presented of 1000 hr dynamic corrosion tests of a variety of reactor structural materials in water under the following conditions: temperature 600 F; pressure—2000 psi; velocity past the specimens—20 fps; inhibitor—100 cc dissolved hydrogen per kilo of water. (auth)—NSA. 16338

8.4.5, 3.4.9

Corrosion of Metals in Atomic Reactors. (In Japanese.) Goro Ito. J. Electrochem. Soc. Japan, **25,** 148-156 (1957) April.

Corrosion of metals by high-temperature water in atomic reactors, corrosion resistance of stainless steel, zirconium-tin alloys and carbon steel; corrosive effects of uranium, uranium salts, molten metals and bismuth. 35 references.—MR. 16226

8.4.5, 3.5.4

Compilation of Organic Moderator and Coolant Technology. Division of Reactor Development, AEC. U. S. Atomic Energy Commission Pubn., TID-7007 [Pt. 2 (Del.)], Jan. 24, 1957 (Declassified with Deletions March 15, 1957), 393 pp. Available from Office of Technical Services, Washington, D. C.

A large amount of information is included on the effects of radiation on organic compounds. Particularly, discussions are included on topics such as the radiation stability of organic fluids, the stability of diphenyl under fast flux irradiation in a dynamic system, the radiation and thermal stability of ortho-, meta-, and para-terphenyls and the radiation damage in organic materials in relation to the type of radiation. Extensive information is also given on the particular applications of organics to use in reactors. Included are detailed discussions on the design and feasibility of an MTR type power producer for remote locations, the analysis of costs attributable to coolant maintenance in a diphenyl cooled reactor, properties of organic coolants, preliminary studies of a hydrocarbon moderated and cooled reactor, the evaluation of organics as reactor moderator-coolants, an Organic Moderated Reactor Experiment, inpile studies for the development of organic moderated reactors and a nuclear design study of diphenyl moderated and cooled reactors. Other topics discussed include a study of the corrosion of natural uranium and magnesium in diphenyl and the intermediate heat transfer system for use with sodium cooled reactors.—NSA. 15731

8.4.5, 1.2.5

The EBR-1 Meltdown—Physical and Metallurgical Changes in the Core. J. H. Kittel, M. Novick and R. F. Buchanan. Argonne National Lab. Nuclear Sci. and Eng., **4,** No. 2, 180-199 (1958) Aug.

As a result of the partial meltdown which occurred in EBR-1 on Nov. 29, 1955, it was necessary to remove core assembly from reactor and to separate enriched fuel section from upper and lower unenriched blanket sections. Fuel section was made up of 2 long bare slugs which were separated by a 0.005 in. thick stainless steel spacer. Lower blanket slug was made of unenriched uranium and encased in a drawn-on stainless steel jacket. Upper blanket section consisted of 2 long slugs encased in a single drawn-on stainless steel jacket. Fuel slugs were separated from jacketed blanket slugs by 0.005 in. thick stainless steel spacers. Although outer jackets were damaged on most of fuel elements in outer row, it was evident that jacket melting which had occurred in these elements resulted from external causes, rather than from fuel slugs which they contained. Examination of several disassembled fuel elements from outer row showed that surfaces of fuel slugs and interior surfaces of stainless steel jackets had not been affected by the meltdown. For outer row of fuel elements, therefore, it appeared that fuel temperature did not exceed about 850-950 C, which have been reported to be lowest temperatures at which uranium and stainless steel will form a liquid phase for short heating periods. Photos, diagrams. —INCO. 17417

8.4.5, 3.2.3

Examination of Specimens and Scales Taken From the HRT Following Runs 13 and 14. G. H. Jenks, A. R. Olsen and W. C. Yee. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-58-9-37, Sept. 11, 1958, 17 pp. Available from Office of Technical Services, Washington, D. C.

Following Homogeneous Reactor Test runs 13 and 14, several metallic specimens were removed from the high pressure systems and transferred to the Materials Section for examination. Samples of scale accumulation in the high pressure system were also taken after these runs and transferred to the Materials Section. Examination and analyses of these several specimens are still in progress, but some of the results are available and are reported. A possible interpretation of some of these results indicates that a considerable quantity of

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nickel was contained in the core scale accumulation at the end of run 13, and that part of this nickel was dissolved in solution during run 14. The amount of nickel which may have come from this source during run 14 roughly accounts for all of the increase in nickel in solution during run 14. A significant amount of uranium was also found in the scale accumulation in the core after run 13. (auth)—NSA. 17387

8.4.5, 3.5.4

Nuclear Engineering Department Progress Report for January 1-March 31, 1958. F. Maslan, Editor. Brookhaven National Lab., U. S. Atomic Energy Commission Pubn., BNL-506, 66 pp. Available from Office of Technical Services, Washington, D. C.

An improved method of drying MgCl before making up sodium chloride-potassium chloride-magnesium chloride eutectic results in a more reproducible uranium partition coefficient in salt-bismuth equilibration. The activity coefficient of zirconium in very dilute bismuth solutions was found to be 7×10^{-4} at 700 C. Annealing of irradiated quartz optical cells at 500 C is reported. The behavior of fission products iodine and xenon in Liquid Metal Fuel Reactor fuel systems was studied. Corrosion tests of several materials in fused salt mixtures are reported. The operation of five in-pile loops is reviewed. Bench contactor experiments are described. Rates of transfer of samarium from bismuth-magnesium-samarium alloy to the ternary eutectic salt mixture were measured for the case of small drops falling through a column of salt. The pumping and corrosive effects of thorium bismuthide slurries were studied. Corrosion of steel immersed in bismuth-magnesium-uranium-zirconium alloy was evaluated. A number of measurements of neutron slowing-down and diffusion parameters were made with graphite, bismuth, and graphite-bismuth mixtures. Satisfactory dissolution media were found for the Enrico Fermi Fast Breeder core. A 15-ft-long clay column experiment with a simulated waste solution spiked with 2c Sr^{90} gave a decontamination factor of 1.6×10^5. The mechanism of Y^{90} bonding to an anion exchange resin was determined. Reactor irradiation of lithium hydroxide produces no detectable O^{20} at currently available neutron fluxes. A satisfactory system was developed for milking As^{72} from its Se^{72} parent. A process for producing pure carrier-free Mo^{99} was developed. (For preceding period see BNL-491.)—NSA. 17484

8.4.5, 3.5.4

Report on the First NPD-1 Single Element Irradiation and Failure. J. Howieson. Atomic Energy of Canada, Lt., AECL-552, August, 1957, 89 pp. Available from the Scientific Document Distribution Office, Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada.

An NPD fuel rod was intended to consist of a bundle of 19 elements each 0.504 in. uranium dioxide diameter, clad in 0.027 in. Zircaloy-2, and 8 ft 9 in. long. This first test was of a single one of these elements under conditions approximating the most severe to be encountered in the reactor. The test was carried out in the E-9 rod position of the NRX Reactor. The heat was removed from the element by high pressure, high pressure water circulated in the loop system. The irradiation started on January 18 and proceeded as planned. On February 26 a hole appeared through the sheath. One of the series of tests called for the operation of a defected rod to observe the activity released in normal operation. The power was lowered to 5 Mw and then raised back to 40 Mw. This caused all the monitors to go off scale. The reactor was shut down and the element removed for examination. It was found that the Zircaloy-2 cladding had corroded and in one place at the center of the rod had corroded completely through and exposed fuel.—NSA. 17003

8.4.5, 4.3.2, 4.3.3

HRP In-Pile Corrosion Test Loops, Operation of In-Pile Loop L-2-19. R. A. Lorenz. Oak Ridge Natl. Lab. U. S. Atomic Energy Commission Pubn., CF-58-6-74, June 19, 1958, 21 pp. Available from Office of Technical Services, Washington, D. C.

Loop L-2-19 operated in HB-2 of the LITR for 1148.9 hours of circulation and 2705 Mwhr of LITR operation. The solution contained 0.17 *m* enriched uranyl sulfate, 0.02 *m* cuppric sulfate, 0.12 *m* excess sulfuric acid and 0.20 *m* lithium sulfate in water. The main stream was 280 C and the pressurizer 295 C. There was no unusual difficulty during loop operation. A revised loop sample procedure gave better flushing of the sample lines. Four valves failed due to severe corrosion and fracturing of the 420 SS stems. I-131 was not detected in a sample of gas taken from the gas hold-up tank. The run was terminated when the circulating pump failed. (auth)—NSA. 17128

8.4.5, 4.7

Feasibility Studies on Molten Metal Reactor Components. Ray W. Fisher and Charles B. Fullhart. Ames Lab. and Iowa State College. U. S. Atomic Energy Commission Pubn., A/CONF.15/P/1032, 17 pp. Prepared for the Second U. N. International Conference on the Peaceful Uses of Atomic Energy, 1958. Available from Office of Technical Services, Washington, D. C.

Several aspects of the design of a successful molten metal reactor are discussed such as corrosion, mass transfer, heat transfer, pumping rates, electrical characteristics, fabrication of various metals and alloys which might serve as possible fuels, blankets or container materials. The electrical resistivity of tantalum, yttrium, Inconel, stainless steel and various fuels are tabulated. The corrosion rate and mass transfer are described for the following system: thorium-magnesium eutectic in tantalum at 800 to 920 C, 95% bismuth-5% uranium (by weight) in tantalum at 950 to 1050 C and uranium-chromium eutectic in yttrium at 900 to 1000 C.—NSA.

8.8 Group 8

8.8.5

Shrinkage Prevention in Bronze Castings. C. L. Frear. Foundry, **86,** Nos. 9, 10, 11; 73-77; 84-89; 96-101 (1958) Sept., Oct., Nov.

Casting design changes, location of risers and use of padding and chills are discussed in relation to preventing, reducing, or minimizing effect of shrinkage in bronze castings. Many diagrams.—INCO. 17256

8.8.5

Overall Summary of Vacuum Melting. C. T. Evans, Jr. Paper before Am. Inst. Mining & Met. Engrs., Electric Furnace Steel Conf., Pittsburgh, Dec. 4-6, 1957. Proc. Elec. Furnace Steel Conf., Am. Inst. Mining & Met. Engrs., **15,** 93-110 (1958).

Description of overall status of vacuum melting industry. Description is given of major features of both older air processes and newer vacuum processes, so that some comparisons can be made and some forecasts attempted of where each technique may find its place in the future production of special metals and alloys. Induction vacuum melting permits use of higher titanium and aluminum contents in a given nickel, cobalt or iron base alloy and good melting practice results in very close control of these hardening elements. Graphs show spectacular growth in stress rupture and ductility specifications for Waspaloy alloy. Tables, diagrams.—INCO. 17247

8.8.3, 3.2.2

Electroplating Baths for Ultra-High-Strength Steels. Pt. I. Use of Aliphatic Amino Acids in Cadmium Baths to Reduce Hydrogen Embrittlement. P. N. Vlannes et al. Naval Research Laboratory, Rept. 4906, March 7th, 1957, 13 pp. Published by the Dept. of the Navy, Office of Naval Res., Washington, D. C. (Order PB 121836.)

Non-cyanide cadmium plating baths containing β-alanine or various δ-amino acids were investigated over a wide pH range to see whether their use might reduce the occurrence of hydrogen embrittlement. Polarography was first used to determine the half-wave potentials of the complexes formed with the acids and so calculate the reduction potentials. Various methods were employed to measure throwing-power and embrittlement. Most of the solutions led to less embrittlement than cyanides, with the δ-amino-n-butyrate and glycinate solutions the best. 5 figures.—ZDA. 16403

8.8.1

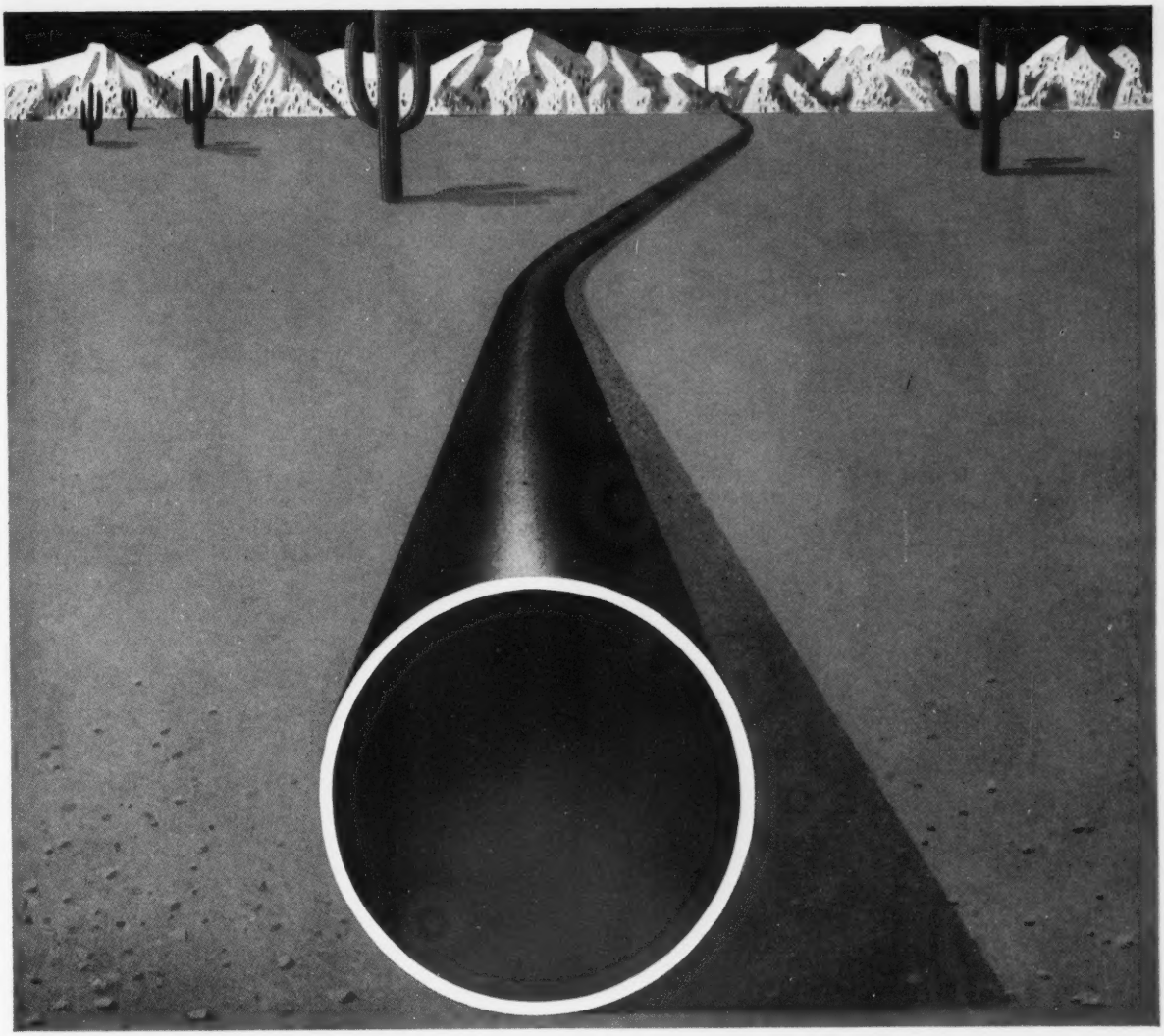
CO_2 Removal from Natural Gas. B. O. Buck and A. R. S. Leitch. Petrocon Eng. Co. Oil and Gas J., **56,** No. 38, 99-100, 102-104 (1958) September 22.

Describes design of a commercial hot potassium carbonate plant for removal of carbon dioxide for specific operating conditions. Carbon steel is adequate for construction throughout the plant, with one exception. Stainless steel is used where velocities of fluid are high. Corrosion from oxygen is controlled by maintaining approximately 0.2 wt. percent potassium dichromate as an inhibitor. Graphs, tables.—INCO. 17326

8.8.3

Some Developments in Barrel Nickel Plating. B. E. Bunce. Electroplating and Metal Finishing, **11,** No. 11, 389-397 (1958) Nov.

Begins with review of published literature on solutions, equipment and operating data for barrel nickel plating. Description is given of investigation undertaken to increase both speed and quality of nickel plating carried out in submerged and partially submerged barrels. Various solution compositions were investigated and effects of certain brightening and levelling agents were noted. Influence of magnesium sulfate and sodium chloride on conductivity was also studied. Success of barrel plating process using modified vat plating solutions is dependent on resistance across barrel panels; the greater the area of holes the better the plating results and the greater the current density that can



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be obtained. Prefabricated Perspex barrel with particularly thin panels and large hole area was preferred. Production of laminated deposits is due mainly to intermittent make and break of electrical contacts within work load during plating. This was reduced considerably by sheathing standard rubber-covered flexible contact cables with polyvinyl chloride tubing. Perspex barrel lid clamps with removable clamping blocks were developed to overcome attack by plating solution of normal rubber or polythene-covered steel clamps. Plating solutions and conditions are tabulated.—INCO. 17301

8.8.5

Slip Casting of Metal Powders. H. H. Hausner. Paper before Metal Powder Assoc., 14th Annual Mtg., Philadelphia, April 23, 1958. Powder Metallurgy Bull., **8**, No. 3/4, 53-67 (1958) June.

Process steps in metal powder slip casting are outlined and variables involved are listed. Properties are compared of an individual powder particle in mass of powder with application of pressure (conventional powder metallurgy) and without pressure (loose powder or slip casting), and effects of these properties on sinterability of powder are discussed. Processing variables of utmost importance in slip casting are viscosity and pH of slip. These factors depend on liquid to metal ratio, and on type and amount of deflocculant. Investigations into slip casting of Type 316 stainless steel powder are described. Tables summarize following data for the Type 316 powder: chemical analysis; particle size distribution and apparent density; properties of alignin used as binder and deflocculant; pH and viscosities of slip; effect of water content on slip conditions and properties (density and green strength) of test specimens; and shrinkage of slip cast and sintered powder. Graphs.—INCO. 17335

8.8.5

Cast Minatures by the Ton. J. H. Cadieux. Casting Engrs., Inc. Machine Design, **30**, No. 25, 27-28 (1958) Dec. 11.

Minicasting process increases output from 1000 to 25,000-50,000 close-tolerance parts per day, and cold sizes or swages parts to cut dimensional tolerances nearly in half. In this automatic investment casting process, plastic patterns are used instead of wax; these are injection molded in multiple-cavity dies. Automation is used to make investment molds, pour alloys, coin, stamp, or swage resulting castings. Suitable metals include high-alloy steels, tool steels, superalloys and stainless steels. Typical castings of 4140 steel, 8620 steel (0.4-0.7 nickel), beryllium-copper and silicon iron are shown.—INCO. 17196

Application of Nitrogen Solubility Data to Alloy Steelmaking. F. C. Langenberg and M. J. Day. Paper before Am. Inst. Mining & Met. Engrs. Electric Furnace Steel Conf., Pittsburgh, Dec. 4-6, 1957. Proc. Elec. Furnace Steel Conf., AIME, **15**, 7-15; disc. 15-16 (1958).

Nitrogen is a potent austenite former and stabilizer, and in combination with chromium, manganese and carbon can be used to develop steels that are comparable to the well established austenitic grades. Effect of temperature on nitrogen solubility is discussed. Temperature has no effect on nitrogen solubility in iron-nickel alloys containing up to 20 nickel. In the ternary iron-chromium-nickel system an increase in temperature from 2900 to 3100 F caused a decrease in nitrogen saturation solubility. Nickel actually lowers solubility of nitrogen in the molten alloy and it is reported that nickel has litle effect on solid solubility of nitrogen in austenite. Thus, improvement in soundness with increasing nickel content is probably due to nickel's action as a strong austenite former. Nickel probably prevents formation of excessive delta ferrite on initial solidification. Application of nitrogen solubility data is given. Graphs, 10 references.—INCO. 17465

8.8.5

Coextruded Parts Can Simplify Design. N. R. Gardner. Materials in Design Eng., **48**, No. 7, 91-93 (1958) Dec.

A coextrusion is produced by forcing 2 or more materials through a die at elevated temperatures. The product is a metallurgically bonded composite of 2 or more materials in a continuous length. Shapes, sizes and tolerances possible with coextrusion are discussed. Coextruded stainless steel-clad molybdenum tubing is used for high temperature structures. Molybdenum and stainless steel serve the separate functions of providing the structure with high temperature strength and good oxidation, respectively. Coextruded zirconium and titanium-clad copper tubing are typical coextruded products providing high thermal conductivity and good resistance to various acid media in a single structure. Such tubing is used in chemical process equipment to achieve high heat transfer rates and maintain long life. An additional example of a heat transfer material is copper tubing clad with stainless steel. Another typical application is platinum-clad electrodes. Photomicrographs, graphs, diagrams.—INCO. 17413

8.8.5

Slice and Electrogrind Honeycomb for B-52 Panels. W. G. Koehler. Aeronca Mfg. Corp. Am. Machinist, **102**, No. 12, 93-95 (1958) June 16.

Aluminum cores are shaped with circular milling cutters and stainless steel cores are electrolytically ground by latest methods and equipment to make full-contact-bonded sandwich structures. Stainless steel cores are cut with modified Anocut electrolytic unit; cutting speed wih 300-amp power pack is 20 ipm when grinding wheel takes a cut 2 in wide and 0.020 in deep. Photographs.—INCO. 17427

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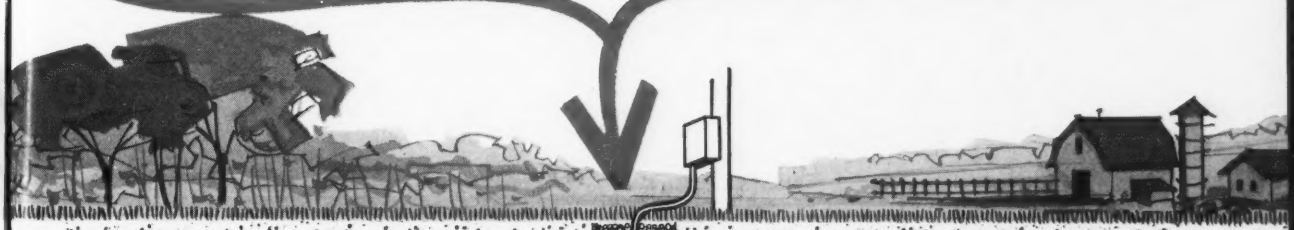

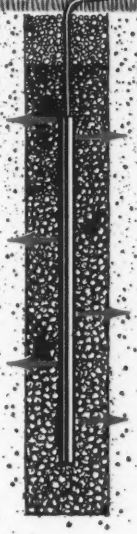

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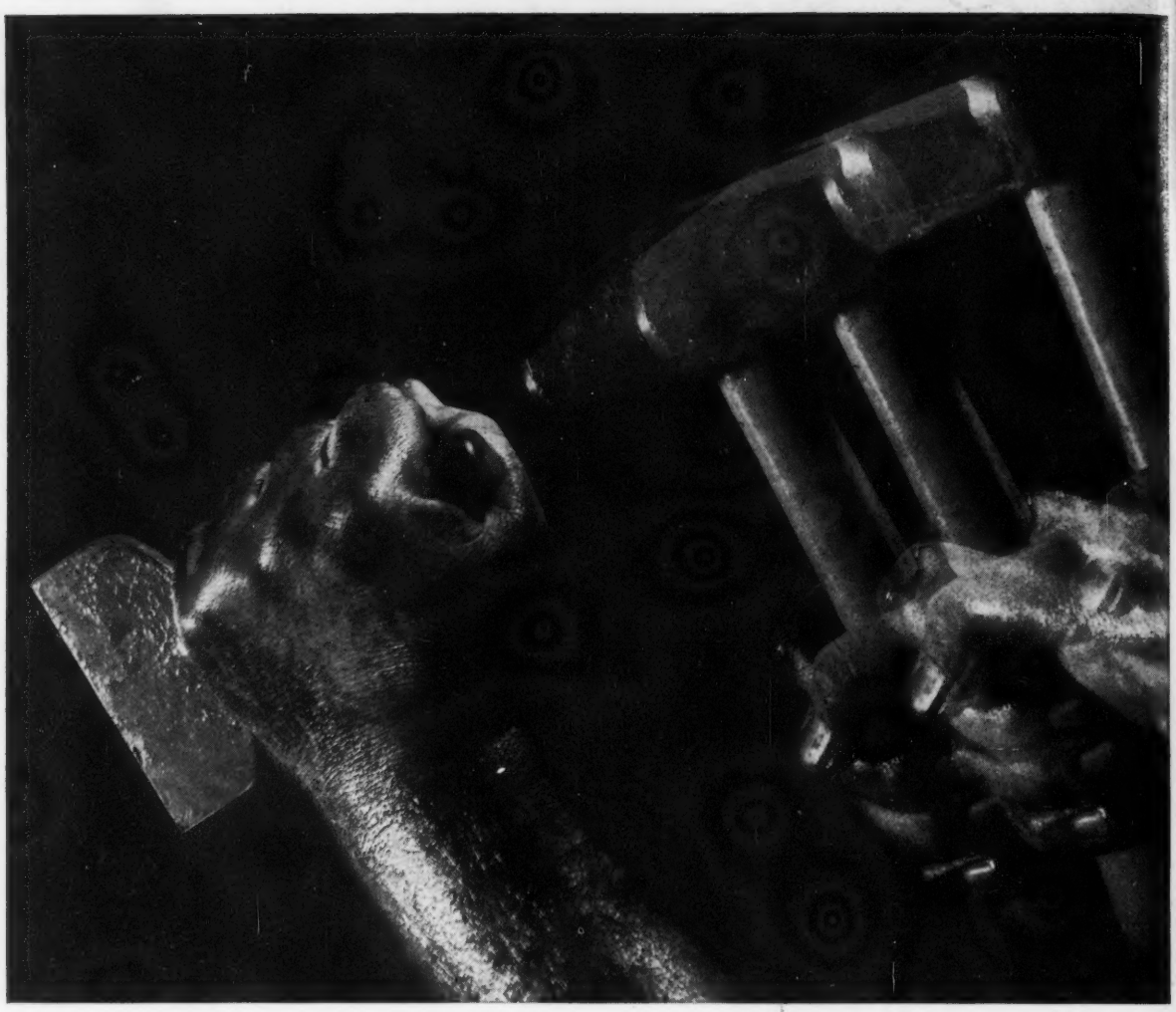

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